THE THRESHER'S GUIDE

VOL. I

Price Fifty Cents

The Thresher's Guide

Vol. 1

BEING A REPRINT FROM THE
THRESHERS' SCHOOL OF
MODERN METHODS OF THE
AMERICAN THRESHERMAN

Published By

The American Thresherman

MADISON, WISCONSIN

FOREWORD

THIS little book has been compiled from the "Threshers' School of Modern Methods." It consists of the lessons on the boiler and engine, beginning with the August issue, 1906, of The American Thresherman.

These lessons were prepared originally in the form of lectures for the farm engineering students of the North Dakota Agricultural College, and were used for several years by Professor P. S. Rose in his class work before he prepared them for The American Thresherman.

Simplicity has been the watchword in the preparation of these lessons. The writer realized that they were for the use of boys and men who had practically no technical training and who wanted something that anyone of average intelligence could understand. Consequently, wherever it has been possible to state a truth in simple words, this has been done. This book contains almost no mathematics and no long discussions of heat and heat units. It is a plain, practical book for men in the field.

A large number of things usually found in other engineering books have been omitted, but that is thought to be an advantage since the things omitted have no direct bearing on the traction engine. On the other hand, there are many things touched upon not found in other engineering books, notably the chapter on reversing gears and on valve setting.

The lessons of this series dealing with the separators are not yet completed and consequently it was deemed advisable to make two volumes of the work and publish both under the title, "The Thresher's Guide." Volume two, dealing with the separator, will follow.

TABLE OF CONTENTS

CHAPTER I.

POWER OF STEAM AND TYPES OF BOILERS.

THE POWER OF STEAM.

Every man who runs a traction engine ought to know something of the magnitude of the force he is working with. He ought to know something about the strength of the materials in his boiler and engine. He ought to know the exact construction of every part of his machine. He ought to know how to make all necessary repairs and make all necessary adjustments, and he ought to be familiar with the scientific laws governing every operation of an engine or any of its parts.

So far as possible without taking up mathematical theory further than can be done with simple arithmetic, the following lessons will present the subject in accordance with the general outline laid down above.

When the writer was asked seven years ago to prepare a course of lectures in traction engineering for the students of the North Dakota Agricultural College, the authorities who were most interested in the work requested that the students be given a lecture on the power of steam, and impressed as strongly as possible with the amount of energy stored within the walls of a steam boiler. The aim being to impress the students so strongly with the magnitude of the force the steam engineer has to deal with, that they would never lose a wholesome respect for a steam engine. This lecture has served its purpose so well that it is offered here without further comment.

The boiler generates the power for the engine and is therefore the most important feature of a traction engine. It is the part that gives the most trouble, the part that wears out first, and the most dangerous part. When properly handled and cared for it is perfectly safe, but the fact must never be lost sight of that it may, if neglected, be one of the most terribly destructive agents that man has to deal with. Comparatively few people who handle steam engines, and especially farm engines, have a clear idea of the power stored within the walls of an ordinary traction engine boiler. It seems advisable, therefore, in the very beginning to present this side of the subject with the hope that it will induce every one who reads this article to give more care and attention to the boiler than it generally receives.

The enormous amount of energy in steam and heated water under pressure is hard to comprehend. Even after seeing the figures they are so large that the mind scarcely grasps their meaning. In order, therefore, to present the matter as clearly as possible we will take for example a well known traction engine equipped with a direct flue boiler. The specifications laid down in the builder's catalogue are as follows: Size of engine, ten by thirteen inches; diameter of boiler shell, thirty-four inches; length of boiler, ninety inches; length of fire box, fifty-two inches; height, twenty-eight and one-half inches; width, twenty-nine inches. Number of flues, ninety; diameter of flues, two and one-half inches. Total weight of engine without water, 22,830 pounds. Weight of water with two inches showing in the glass, 3,250 pounds. As traction engines are commonly rated this would be properly a 25-horse power engine. The number of cubic feet of water in the boiler was found to be fifty-two, and the steam space about twenty-six cubic feet as nearly as could be estimated. This gives a ratio of two cubic feet of water space to one of steam, which is about right for boilers of this class. The steam pressure was taken at 150 pounds gauge pressure and the computations made accordingly.

From Thurston's Manual of the Steam Boiler

Steam Pressure above a vacuum in pounds per square inch	Temperature in degrees Fahrenheit of the steam and the water from which it was formed	Amount of energy in foot lbs. contained in 1 lb. of water, which may be set free by explosion or expansion to atmospheric pressure	Total number of foot lbs. of energy contained in one lb. of steam at corresponding temperature and pressure
20	227.9	145.9	17018.8
30	250.2	813.5	39735.4
40	267.1	1645.7	55757.4
50	280.8	2550.4	68164.2
60	295.2	3449.2	78333.8
70	302.7	4361.1	86938.8
80	311.8	5206.5	94345.2
90	320.0	6058.1	100872.8
100	327.5	6885.2	106672.8
110	334.5	7689.0	112023.9
120	340.9	8483.1	116808.5
130	347.0	9252.6	121278.2
140	352.7	9992.6	125374.7
160	363.2	10536.5	129003.7
165	365.7	11823.4	134521.2

The weight of a cubic foot of steam at 150 pounds pressure is shown by the steam tables to be .374478 of a pound, which multiplied by 26, the number of cubic feet of steam in the boiler, gives 9.73

pounds of water in the form of steam. Each pound weight of steam at 150 pounds gauge pressure contains 134,521.2 foot pounds of energy which may be set free by explosion, as will be seen on referring to the accompanying table. This number multiplied by 9.73 gives a product of 1,308,887.3, which represents the total number of foot pounds of energy stored in the steam alone.

Since water in a boiler at 150 pounds pressure has a corresponding temperature of 365.7 degrees Fahrenheit, it also contains a great amount of energy which may be set free by explosion. Pound for pound there is not as much energy in the water as there is in the steam, but there are so many more pounds of the former than of the latter that the total amount of energy in the water greatly exceeds that in the steam.

Cold water is not explosive at any pressure because water is not compressible, and consequently it has no tendency to expand when the pressure is removed. Hot water, however, if hotter than 212 degrees Fahrenheit, has a certain amount of explosive energy depending upon the pressure and corresponding temperature, because the heat that it contains above 212 degrees will, in the case of an explosion, turn a large amount of the water into steam, which of course has a tendency to expand. The amount of energy in one pound of water at 150 pounds pressure which might be set free by explosion is shown in column 3 of the accompanying table to be 11,823.4 foot pounds. In 3,240 pounds of water, (the small decimal was dropped to avoid fractions) there are 11,823.4 times 3,240 or 38,307,816 foot pounds of energy in the water, which added to the energy in the steam makes a total of 39,616,703.3 foot pounds of energy stored within the walls of a boiler and which would be set free to do destructive work in case of an explosion.

If this energy could all be applied as the powder is in a rifle to shoot a ball weighing one pound vertically into the air, it would be sufficient to hurl such a missile the almost incredible distance of 39,616,703 feet, or almost 7,500 miles. A ball traveling with velocity enough to go so far would undoubtedly pass beyond the earth's attractive force and would forever afterward circle through space as a meteor. In order to get a still clearer idea of what such a tremendous amount of energy means, we will see what would happen if, instead of applying the power to a ball weighing only a pound, we applied it in the same way to the whole engine weighing, as before stated, 22,830 pounds. A little calculation shows that it would leave the earth with a velocity of 384.2 feet per second and rise to a height of 1,735 feet, almost one-third of a mile. At such a height

it would appear a mere speck in the sky, sailing high above most of the clouds. Or if this total amount of energy were applied to a cannon ball weighing one ton, it would shoot upward with a velocity of 1,101 feet per second and finally reach an elevation of over three and one-half miles.

The above illustrations point out more clearly than mere figures the tremendous amount of energy the traction engineer has at his command. They also, it is hoped, emphasize the necessity for keeping this force under control.

Some men through ignorance, and others through long experience, acquire a certain contempt for the power of steam. They do not hesitate to run any sort of an engine or to carry any pressure that suits their fancy. The gauge may be wrong or the pop valve may be wrong or the water be low, but these men have no fear because they do not realize the risk they are taking. Such men and those that work with them are in constant danger, for steam is no respector of persons. It is a good servant or a merciless destroyer, depending upon how it is handled.

The writer once heard a fellow say concerning an old condemned Ames boiler, "I am not afraid to run that engine; I'd just as soon run that machine as any in the country." That fellow was not brave, he was just a plain fool, and he did not know when he made that remark that he was advertising the fact that he was not an engineer. A good engineer would not say such a thing; he understands the danger too well and will not take unnecessary chances; on the contrary, he takes every precaution to make both life and property safe. He should have plenty of nerve and a cool head in case danger does arise or he will be a poor man to put in charge of machinery. A man never becomes a good traction engineer until he gets over a certain nervousness that all beginners experience when they first begin to work with an engine, but when that time of self confidence arrives he should guard against feeling too sure and becoming careless and reckless. While the lesson just presented may seem to be calculated to inspire fear of an engine, the fact is that no such result is anticipated. There is a difference between fear and proper respect. This lesson is intended merely to inspire respect for an almost limitless force, with the hope, as before stated, that it will induce those engineers who read to be more careful.

TYPES OF BOILERS.

Taking up the subject of boilers in a general way without especial reference to the traction engine, we find that they may be classified in several ways. To begin with, they may be divided into two

main classes, one comprising those which are internally fired, and the other those that are externally fired.

Internally fired boilers are provided with a fire box or furnace within its own walls. All locomotive boilers, traction engine boilers, marine boilers, and many boilers used in stationary engines belong in this class.

Externally fired boilers are placed over a furnace built especially for them and are set in a brick setting. They are therefore not designed for portable purposes, and find their widest application for mill and factory work and for central heating plants.

These two classes may be again divided into two more classes depending upon the course taken by the hot gases, one being composed of shell or tubular boilers, known as fire tube boilers, and the other as water tube boilers.

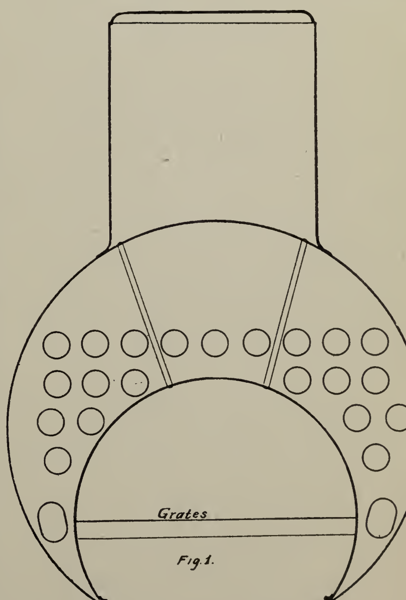
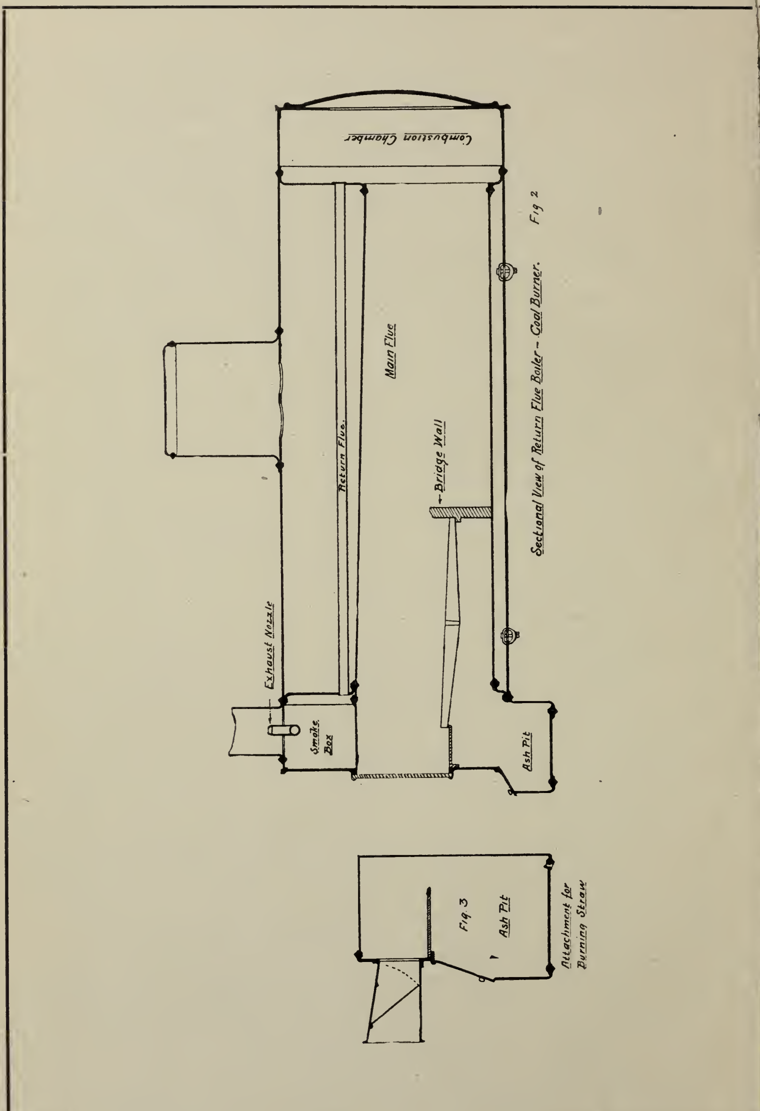


Fig. 1.

End View of Michner Boiler.

In the fire tube boiler the hot gases pass through the inside of the tubes or flues on their way to the chimney, and water circulates about the outside. In the water tube boiler these conditions are reversed, water occupies the space inside the tubes and the hot gases pass on the outside. Both types of boiler have certain advantages peculiar to themselves. The water tube boiler is a quicker steamer than the fire tube because there is no large mass of water in one body to be acted upon by the hot gases, since it is very effectually broken up by the large number of water tubes. Boilers of this class are also less liable to a dangerous explosion, for if an explosion does occur at all, only one or two tubes are likely to let go, in which case no great damage either to life or property is apt to take place. On the other hand, these boilers are much more expensive than fire tube boilers and are much harder to keep in good working order. Many manufacturing plants and some steam



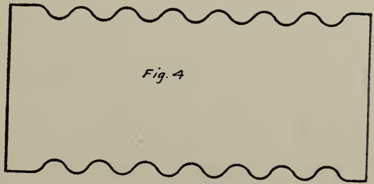
Sectional View of Return Flue Boiler – Coal Burner. Fig 2

Fig. 3 Attachment for Burning Straw

ships are equipped with boilers of this class, but all locomotive boilers, and all traction engine boilers, with but one exception, are of the fire tube class.

Boilers may also be classified according to form as either horizontal or vertical. Vertical boilers are not as efficient as horizontal ones and are not generally used except where there is plenty of overhead room and floor space is very valuable.

In stationary practice there are a great many different conditions to meet and a great variety of work to be performed, thus giving rise to a large number of different types of boilers, but in traction engineering the case is different. The work a traction engine has to perform is practically the same everywhere, whether it is used in threshing, plowing or freighting; consequently there are not so many types of boiler in use as in stationary practice. At the present time nearly all traction engine boilers may be divided into two classes, the fire box direct flue boiler and the return flue, with the direct flue considerably in the lead as to the number in active use. Both types of boiler have been used for a great many years and both have given satisfaction to their users. Since both have their strong points and both have defects, a discussion of which will be given later, it seems well to call the reader's attention to the fact right here that it is impossible to construct a boiler or any other piece of machinery that is entirely perfect. The best the designer of machinery can do is to compromise what, in his judgment, are the least vital points, and consciously or unconsciously this is just what he does do in every case.



Corrugated Main Flue.

When the wheat raising prairie states were being developed, it became necessary to invent a boiler that would burn straw, on account of the high price of wood and coal and the difficulty of getting it at any price. One of the first really successful straw burners was the Michner return flue boiler shown in Figure 1. The boiler was a good steamer and was built of good material, but it violated two of the first principles of correct boiler design. One portion of the boiler,

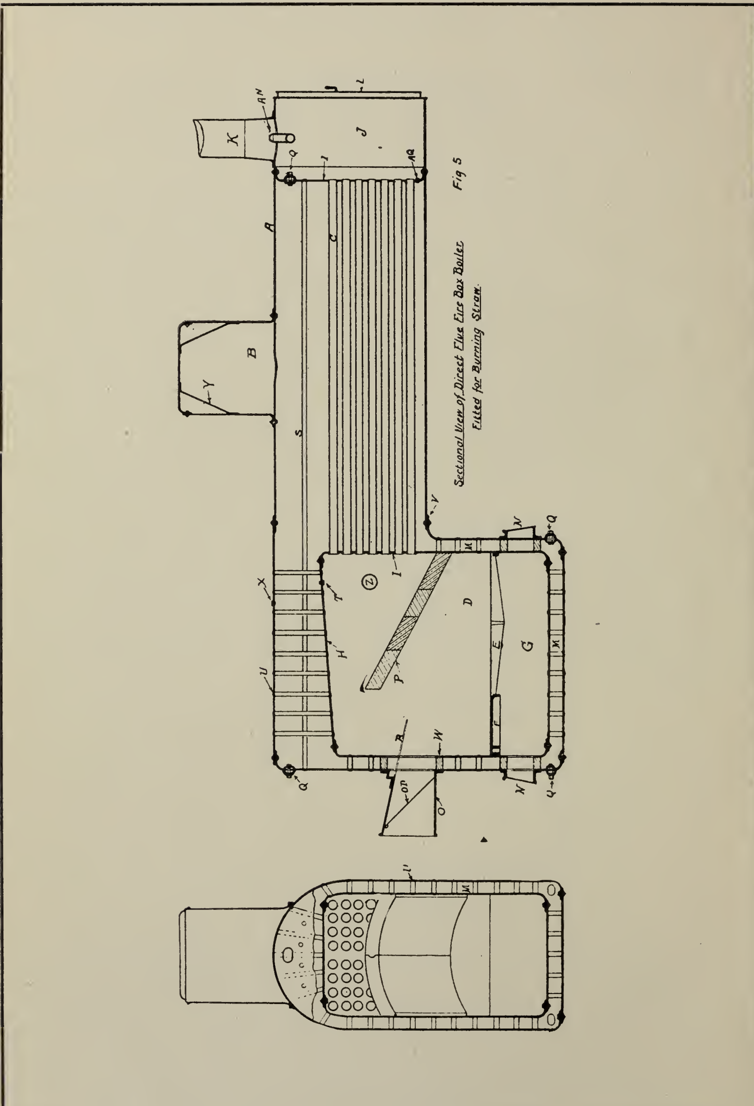


Fig 5

Sectional View of Direct Flue Fire Box Boiler Fitted for Burning Straw.

the V-shaped space between the main flue and the shell, was difficult to clean thoroughly, and the lower sheet in the main flue was not protected by water on the side opposite the fire. As a result of these two defects, these boilers, after a few years' use, became burned and weakened at these two points, and became exceedingly dangerous. A great many of them blew up, killing members of the crew and damaging property. Since then very great care has been exercised generally in building traction engine boilers, with the gratifying result that they are now as safe as any other class of boiler on the market.

Figure 2 represents the leading features of the return-flue boiler. Different companies modify the details of construction to some extent, but the principal features remain the same. For example, some manufacturers provide the combustion chamber with an annular water-ring connected with the main water space of the boiler, while others merely put in a fire brick lining to protect the metal in the walls of the combustion chamber. This type of boiler is a modification of the Scotch boiler so long used and so favorably known in stationary practice. Figure 2 shows the boiler used as a coal burner, and Figure 3 shows the arrangement of the fire box and grates when burning straw. In straw burners the grates are placed slightly above the center of the main flue.

Among the good features of this type of boiler may be mentioned its absence of flat plates and of stay bolts, its cheapness of construction, and the comparative ease with which it may be cleaned. Having no low hanging fire box it is raised above the ordinary obstructions in the road, which is of considerable advantage in rough, stony ground, a feature which has caused this type of boiler to be used largely for freighting in mountainous districts.

To offset these advantages it has a relatively small fire box and a small ash-pan, which necessitates considerable care on the part of the fireman to prevent the ashes from filling under the grates and thus burning them out. By making the main flue larger these defects might in a measure be overcome, but this on the other hand introduces an element of weakness, since it is a well-known fact that a tube is less liable to withstand external pressure than internal, and its strength rapidly diminishes as its diameter increases. Consequently in all traction boilers built east of the Rocky Mountains the size of the main flue is made as small as possible, ranging only from 24 to 28 inches in diameter. On the Pacific Coast, however, some boilers are built with main flues upwards of four feet in diameter which are reinforced by being corrugated, as shown in Figure 4. This adds considerable strength to the flues, but at the same time makes

a convenient place for the accumulation of sediment and scale. The main shell in these boilers is large in diameter for the amount of power developed, and this, added to the fact of a smoke stack in the rear end is considered a valid objection by some good engineers.

Figure 5 represents a direct flue, locomotive fire box boiler adapted for burning straw. All principal parts are lettered and their names appear in the following key:

A represents the shell; B, the dome; C, the flues; D, the fire-box; E, the grates; F, the dead-plate; G, the ash-pit; H, the crown-sheet; I, the flue-sheets; J, the smoke-box; K, the chimney; L, the smoke-box door; M, the water-leg; N, the draft doors; O, the straw chute; P, the fire brick arch; Q, the handholes; R, fingers for guiding the straw; S, a through stay; T, the fusible plug; U, the stay-bolts; V, the waist seam; W, reinforcing rings about openings; X, the filling plugs; Y, are diagonal stays; Z, small door on side of boiler for cleaning the end of the flues; AQ, cleaning plug; AN, the exhaust nozzle; OD, door in straw chute.

The particular advantages claimed for this type of boiler are: the small diameter of the main shell, a feature which adds strength, for it can easily be proven that with the same thickness of metal a tube becomes stronger as its diameter becomes less; its neat appearance, its large fire box, large ash-pan, and large grate area, which make it an easy boiler to steam and one that is easy to crowd in case of emergency, and lastly, the convenient arrangement of valves and levers made possible by having the smoke stack on the front end. In connection with these advantages there are of course some inherent defects, among which may be mentioned the flat plates of the rectangular fire box and the large number of stay-bolts necessary to hold it in shape, both of which will presently be shown are in some respects elements of weakness; added to this is the difficulty of cleaning, the liability of burning the crown sheet and the danger of the low-hanging fire box dragging in the mud in going over soft ground or catching obstructions in the road.

The tendency of pressure within a boiler is to make all flat plates assume a spherical or semi-spherical form, thus placing them under two kinds of strain, viz., bending and tension. It is, therefore, necessary to put in stay-bolts or braces to support all the flat plates, such as the walls of the fire box, the top of the dome, and that part of the flue-sheets above the flues. The flues act as tie-rods for the space they occupy. The number of stay-bolts and their size depends upon the thickness of the boiler plate and the steam pressure carried. Rules have been laid down covering these points and all boiler makers are governed accordingly. In traction engines each stay-bolt supports approximately twenty square inches of surface.

The objections to this form of construction lie in, first, the difficulty of cleaning occasioned by a large number of stay-bolts; second, the added strain placed upon stay-bolts and upon the unsupported part of the plate in case one breaks; and third, the possibility of corrosion at the point where the stay-bolt penetrates the plate. While these objections hold good to a greater or less extent, the fact must not be lost sight of that these boilers have stood the test in the field and have honestly earned their popularity.

In Figure 5 the flue sheets are braced by what is called a through stay, that is, a rod passing through both flue sheets and riveted at each end. There are, however, two other methods of bracing in common use. One is by means of diagonal stays from the flue sheet to the upper part of the boiler shell similar to those shown in the dome in the illustration. The other is by means of a girder stay riveted across the flue sheet and illustrated in Figure 6. When the girder stay is used it is usually placed above the flues in the front end, and diagonal stays are used in the rear. All of these methods of staying are effective and appear to have about equal merit.

In addition to the two types of boiler above discussed, two other types may also be mentioned: the fire box return flue boiler, and the water tube boiler previously alluded to. The former differs from the ordinary return flue boiler in having a fire box or furnace like the direct flue boiler, but in all other essential respects it is like the return flue boiler above described. A large number of these boilers are still in use, but, so far as the writer is aware, they are not now built by any of the traction engine builders, having been supplanted in very recent years by the direct flue type.

Fig. 6.

The only water tube boiler built for traction engine purposes is made by the Westinghouse Company, of Schenectady, New York. This boiler consists of a vertical shell surrounding a central portion which contains the furnace and water tubes. The latter are placed horizontally in courses at right angles to each other and circulation is provided for by means of baffle plates at the ends of, and between the sections, which causes the water to pass from one set of tubes to another. The hot gases pass through the central part of the boiler through the space occupied by the water tubes. The outer shell is bolted to the lower portion and encloses the main water space, and the steam space at the top. This boiler is a quick steamer and quite efficient, but for traction engine work it is manifestly not very well adapted to the large sized rigs used in the West.

CHAPTER II.

KIND OF MATERIALS AND BOILER DETAILS.

MATERIALS USED IN CONSTRUCTION.

Nearly every manufacturers' catalogue contains specifications of the materials entering into the construction of his machinery. This information is, in the main, accurate and instructive, but is very imperfectly understood by the majority of people who read such literature. Probably not one person in one hundred, on the average, can give anything like a definite statement concerning the properties of the ordinary materials used, and it is not likely one in a thousand knows what is meant by the term open hearth flange steel or knows the difference between open hearth steel and tool steel. It seems desirable, therefore, before taking up the details of construction of a boiler or engine, to devote some time to a consideration of the properties, and the processes of manufacture, of the common materials dealt with in everyday work.

Until comparatively recent years the principal material used for boiler plate was wrought iron, but for a number of years back practically all boiler plate has been made of a soft grade of steel.

Steel is manufactured principally by three distinct processes, viz., the open hearth, Bessemer, and crucible processes. A detailed account of each of these processes would be interesting, but it is a little beyond the limits of this book. Suffice it to say, however, that boiler plate is made by the open hearth process, railroad rails by the Bessemer, and steel, used for tools, by the crucible process. This gives some idea of the characteristics of the steel made by each of the different processes.

The materials used in boiler and engine construction are cast iron, malleable iron, wrought iron, steel, brass, bronze and babbitt, a description of the properties of each of which is given herewith.

Cast Iron.—Cast iron is used for brackets, grates and engine castings (including cylinder frame and other parts which require stiffness and considerable weight). It is generally brittle and untrustworthy, being full of flaws and of uncertain texture. In tension it will stand a strain of from 15,000 to 20,000 pounds per square inch, but in compression it will stand from 80,000 to 120,000 pounds per square inch. Gray castings are made from a good grade of pig iron and are easy to machine. Ordinary castings made from scrap iron are harder to work, somewhat more brittle, and often somewhat stronger.

Cast iron is apt to crack under sudden and excessive changes of temperature. It is not suitable for the shells of boilers and is not so used, except in the case of certain styles of low pressure sectional boilers used for house heating, where the pressure does not exceed ten or fifteen pounds to the square inch. Cast iron can neither be forged nor welded.

Malleable Cast Iron.—Malleable cast iron as the name implies, is quite soft and will stand considerable bending before breakage occurs. Malleable castings are used extensively in harvesters, mowers and in other agricultural machinery where considerable strength with light weight is desirable, and to some extent for light castings on traction engines. They are first made like ordinary castings and then packed in a substance rich in oxygen and placed in a special form of oven where they are maintained at a high temperature for several days. During this process a large amount of the carbon, always present in cast iron to the amount of five or six per cent, is either burned out or changed from the graphitic to the combined form, thus making the castings malleable. It is the presence of carbon in the form of graphite, together with the loose structure of the iron, that makes ordinary cast iron so brittle.

Wrought Iron.—Wrought iron differs from either cast iron, malleable iron or steel. It is tough and fibrous in structure, works readily in the forge and is easily welded. The only way to tell the difference between wrought iron and steel is by the appearance of the fracture. When wrought iron is broken the fibers are plainly visible and between them particles of an impurity called slag which has not been squeezed out in the process of working. The more wrought iron is worked under the hammer at the welding temperature, the better it becomes, because more of the slag is worked out. When steel is broken it shows a granular surface. To the experienced eye, the crystals indicate quite clearly the character of the steel. The principal use for wrought iron in traction engine construction is for reinforcing rings at the bottom of the water leg and around fire door openings. It does not crack, and resists the stresses due to extreme differences in temperature better than almost any other substance.

Steel.—Carbon is an essential element of steel but not of wrought iron, although wrought iron always contains more or less of this element. The effect of carbon upon steel is to make it harder, more brittle, and give it the capability of taking a temper. Since boiler plate must always be soft and ductile it is evident that it must contain a very small amount of carbon, consequently the mild steel used in boiler construction contains only from .15 of one per cent to .20

of one per cent of carbon. Machinery steel, which is the kind designated for shafting, contains about one-half per cent of carbon. Such steel will take a mild temper but does not contain enough carbon to make it brittle. Steel containing from .75 up to one per cent of carbon is used for making cold chisels, axes and other tools of the same general nature. The finer grade of tool steel used in making fine cutlery, razors, etc., contains from one to one and one-half per cent of carbon. Such steel is very hard and brittle and is not suitable for any other purpose than for tool making.

Mild steel is worked quite readily in the forge and can be welded but not with the same ease as wrought iron. Steel or iron containing sulphur is brittle when hot and is said to be "hot short." If phosphorus is present in an appreciable quantity it is said to be "cold short," that is, brittle when cold; consequently, care must be taken in the manufacture of steel to keep the percentage of these two injurious elements very low.

Testing Steel.—The suitability of steel for boiler purposes is determined by certain chemical and physical tests which will presently be described. The chemical test is for the purpose of determining the amount of carbon, sulphur, phosphorus and other elements present, and the physical tests to determine the strength, softness, ductility, etc., of the metal.

Physical tests are divided into two classes, tension tests and bending tests. The tension test is for the purpose of determining the ultimate breaking strength of the material, together with its elasticity and stretching qualities; the bending test, in order to determine its hardness, brittleness, etc.

For the tension test, strips two inches wide and about eighteen inches long are cut from the plate to be tested. These test pieces are placed in a testing machine which pulls the specimen in two and registers the number of pounds of tension required on a scale beam. As the load is applied, the specimen begins to stretch and up to a certain point will return to its original length when the load is removed. This point is called the yield point or the elastic limit of the metal.

The bending test required of boiler plate is that the specimen will stand bending and hammering over on itself cold without showing any cracks or flaws on the outside of the bend. It must also stand the same test after being heated to a cherry red and quenched in cold water.

Boiler Steel Specifications.—Four grades of steel are used for boiler purposes, viz., extra soft steel, fire box steel, flange steel and rivet steel.

Extra Soft Steel.—Extra soft steel should stand a breaking strain of from 45,000 to 55,000 pounds per square inch and show an elastic limit of one-half this amount. It should also show an elongation or stretch of twenty-eight per cent in a length of eight inches before breaking. It must also stand both bending tests above described and contain not to exceed .04 per cent of either sulphur or phosphorus.

Fire Box Steel.—Fire box steel must show an ultimate tensile strength of from 52,000 to 62,000 pounds per square inch, an elastic limit of one-half this amount and an elongation of twenty-six per cent in eight inches. The tests for bending, for sulphur and for phosphorus are the same as above.

Flange Steel.—Flange steel must show the same ultimate strength and elastic limit as fire box steel, but the required elongation in a length of eight inches is only twenty-five per cent. The amount of phosphorus allowable is somewhat higher, being .06 per cent, and of sulphur .04. The bending tests are the same as those above specified.

Rivet Steel.—Rivet steel must have the same properties as those specified for extra soft steel.

Metals for Boxes.—Bearings for journals are made of some soft material if the shaft is of any considerable size. The bearing materials in common use are babbitt, brass, bronze and phosphor bronze. In light, delicate machinery, where friction must be reduced to a minimum, very true hard bearings and journals are used, as for example, the jeweled bearings in watches. In ordinary machinery such bearings would not give good satisfaction for several reasons. They would have to be made perfectly true and would hence be very expensive. They would be more easily broken and more difficult to repair, while with ordinary steel shafting and soft boxes all these difficulties are obviated. A good bearing for farm machinery should be easy to repair or renew in the field at slight expense. It should also wear well and sustain the heaviest loads without heating. All bearings, it is true, heat some, and after running for a time will feel quite warm to the hand, but after that the temperature should not increase appreciably in a well made, well designed bearing.

The metal for a bearing should be an alloy composed of two or more metals, one rather hard and yielding, the other somewhat soft and springy. The object of the softer metal is to form an elastic support for the hard metal which really forms the true bearing. As noted above, the harder the metal the less the friction, provided the fitting is done with absolute accuracy; but since hard metals will not conform to the shape of the journal a springy support is

necessary, otherwise the load will be concentrated upon a few high places and produce rapid abrasion and heating.

There are five metals used in making bearings, viz., copper, tin, lead, zinc and antimony. All babbitts, brasses and bronzes are made up of two or more of these metals, with occasionally a small quantity of some other metal. All alloys of copper and tin were formerly called bronzes, while all alloys of copper and zinc were known as brasses. At the present time there is no sharp line of difference between the two, since nearly all alloys contain not only tin but lead and zinc also.

Phosphor-bronze contains about eighty-nine per cent of copper, ten per cent of tin and one part of phosphorus. The object of the phosphorus is to make the bronze harder and tougher. It is perhaps a little better bearing metal than ordinary brass. Ordinary brass contains about 84.3 per cent copper, 10.5 per cent of tin and 5.2 per cent of zinc.

Brasses and bronzes, when used as bearings, reduce the amount of heating and show a little less friction than babbitt, but the difference is only small at best. Babbitt is very much cheaper in first cost and can be repaired so easily in the field that it ranks high as a material for bearings in farm machinery.

Babbitt.—Genuine babbitt contains 3.7 per cent copper, 89.1 per cent tin and 10 per cent of antimony. The large amount of tin makes it rather expensive so that very little genuine babbitt is used for bearing purposes. Cheaper babbitt containing lead with small amounts of tin and antimony are more commonly used. A fairly good babbitt is made up of twenty parts tin, seventy parts lead and ten parts of antimony. It is not quite as good a bearing material as the genuine babbitt but costs only a fraction as much, since lead, which is the base of the alloy, is quite cheap.

Most of the anti-friction metals advertised widely as the "best on earth," etc., are in reality cheap babbitts, composed largely of lead but sold at a fancy price. Babbitt is very easy to adulterate and hard to judge. The only way to secure a good babbitt is to buy from a reputable dealer and depend upon his word for the quality of the material purchased.

A FEW BOILER DETAILS.

Flues.—The flues are made of wrought iron or mild steel and are either lap welded or solid drawn. The steel tubes used for traction engine work are seamless, i. e., drawn and formed to the proper size and shape without being welded. Wrought iron tubes are made of a specially soft grade of iron and are welded over a mandrel. In

general, steel tubes are truer to size and shape and smoother than iron, and as made at the present time are very saisfactory for traction engine work.

All boiler tubes are supposed to stand a water test of five hundred pounds to the square inch internal pressure and a section cut from the tube must stand hammering down cold, vertically, without splitting or showing any cracks or flaws. The length of these test sections vary for the different sizes of tubes, the sections being one inch long for tubes from two to two and one-half inches in diameter. The thickness of boiler tubes is expressed by the numbers of the Birm-

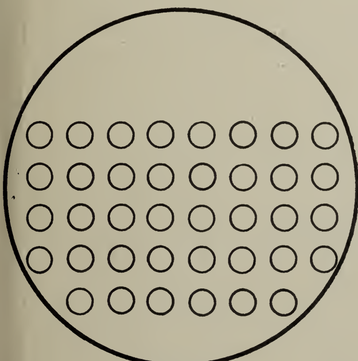


FIGURE 7.

CORRECT.

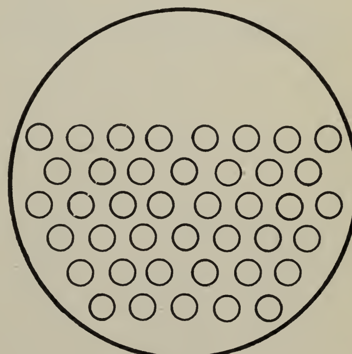


FIGURE 8.

WRONG.

ARRANGEMENT OF FLUES.

ingham Wire Gauge; 12 gauge is the standard for tubes bewteen two and two and one-half inches in diameter, although some manufacturers claim to use 11 gauge for tubes of this size, which is a little thicker.

Flues are measured externally, i. e., a two-inch flue is two inches in diameter on the outside. Steam, gas, and water pipes, on the contrary, are measured internally; for example, a two-inch steam pipe is two inches in diameter on the inside.

The Arrangement of Flues.—The arrangement of flues in a boiler is an important matter and in past years some mistakes have been made by manufacturers in arrangement. At the present time, so far as known, the arrangement of flues in direct flue boilers is in both horizontal and vertical courses, as shown in Figure 7. This arrangement is much better than shown in Figure 8, in which the flues are staggered in vertical rows. Such an arrangement impedes the circulation and does not allow the scale to drop to the bottom,

while at the same time such arrangement makes the boiler very difficult to clean. It is just as essential to have good circulation in a boiler, so far as steaming qualities go, as it is to have plenty of heating surface; in fact, this is another principle in correct design.

Flues are secured in the flue sheets by being expanded at the ends and then beaded over at both ends, or else by being simply expanded at one end and expanded and beaded at the other. Figure 9 shows a tube expanded and beaded and Figure 10 a tube simply expanded. Both methods are in common use and have been for a good many years and both have proven satisfactory in practice.

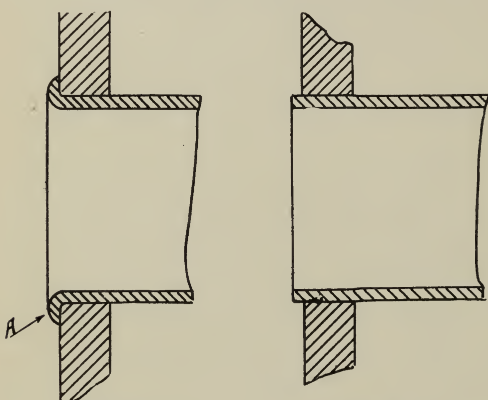


FIGURE 9. FIGURE 10.

FLUE ENDS.

Tests made on the holding power of beaded flues and flues that are simply expanded in the flue sheets show about the same results. It would seem as though the beaded flue ought to hold a good deal more, but the tests show very little difference. Where flues are beaded care must be taken to make the bead, especially in the firebox end, as small as possible. If it is made large it is almost sure to be poorly formed, thus making a poor joint between the flue and flue sheet, as shown in Figure 11. Or even if well formed, the large mass of metal in a big bead, being so far away from the water, does not conduct the heat rapidly to the water, and, hence, is pretty sure to become burned before it has been long in use. Quite a good deal of the difficulty experienced with leaky flues arises from just this cause.

A great many manufacturers, both of traction engines and locomotives, place a copper ferrule between the tube and tube sheet in the fire box end. When the tube is expanded, the copper being much softer, fills whatever little inequalities there are between the two surfaces and thus makes a tight joint. Furthermore, since copper expands very much more than iron for the same increase in temperature, it follows that the joint will be tighter when the boiler is steamed up than when cold. This is the reason why boiler tubes will

sometimes leak when cold and be perfectly tight after the boiler is steamed up. The one objection to the use of copper ferrules is the fact that the alternate contraction and expansion of the metal finally presses the copper out of shape and makes a leaky joint.

Where the holes for the tubes are reamed perfectly true and the flue is turned to a perfect fit, so that bright surfaces come in contact, a very satisfactory joint can be made without the use of copper, but however made there is bound to be more or less difficulty with leaky flues, due to the fact that they are made of thinner material than the flue sheets and consequently expand and contract rapidly with sudden changes in temperature.

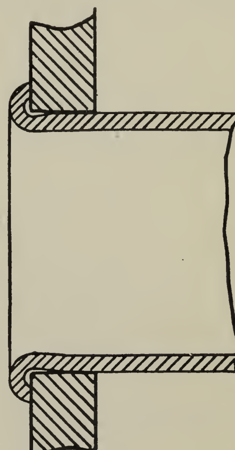


FIG 11. BEAD TOO LARGE.

Whenever the fire door is opened and cold air is allowed to pass through the flues there is a very great drop in temperature, probably of anywhere from 500 to 1,000 degrees, which causes the flue to shrink. Care should be taken, then, to keep the fire door closed while the engine is running and in every way possible to prevent any sudden changes in temperature.

Figures 12, 13 and 14 represent the tools used for putting in flues. Figure 12 is a beading tool, 13 a spring expander, and 14 a roller expander. Every engineer ought to have a beading tool,—which any good blacksmith can make, in his tool box. In making this, care should be taken to make the radius of curvature at *A* of the right size, because the size of the bead on the tubes will be dependent upon the size of this curve. Either one of the expanders will do good work. For repair work,

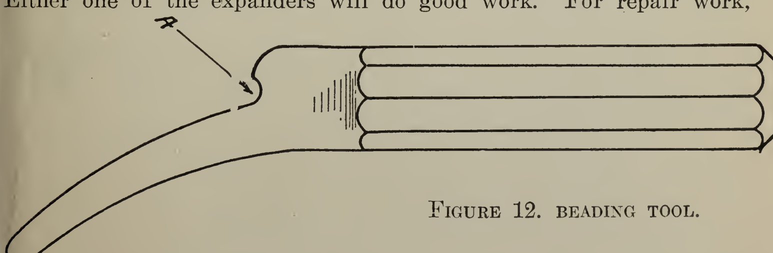


FIGURE 12. BEADING TOOL.

where the holes in the flue sheet may be slightly out of round, the spring expender will probably do the better work; for new work, the roller expander is very satisfactory.

In putting in flues care should be taken, first to anneal the ends, which can be done by heating them to a bright cherry red and then allowing them to cool in slaked lime, dry ashes or dry sand. They should be cut off square on the ends, preferably in lathe, and an

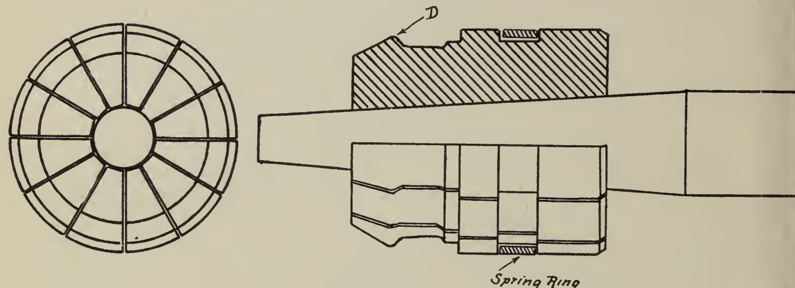


FIGURE 13. SPRING EXPANDER.

allowance provided of between one-eighth and three-sixteenths of an inch at each end for beading or for projection if they are not beaded. After the tubes are in position the expander is driven in fairly tight, the taper pin is then jarred loose, the pin turned slightly, then driven in again, and this operation repeated until a tight joint is secured between the tube and tube sheet. Care should be taken

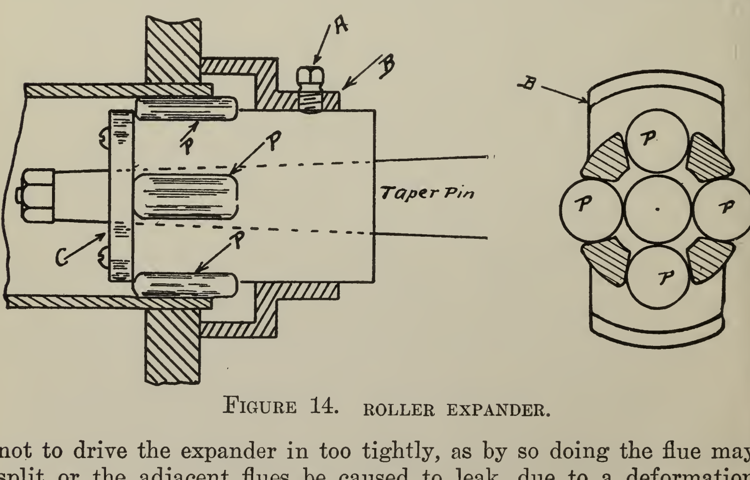


FIGURE 14. ROLLER EXPANDER.

not to drive the expander in too tightly, as by so doing the flue may split or the adjacent flues be caused to leak, due to a deformation of the tube sheet.

The work done by the spring expander whose operation has just been described is shown in Figure 15. The convex portion at D forms the groove shown at B in the figure. After the tubes are expanded the bead is generally started with the ball-pene of a machinist's hammer and then finished up by means of the beading tool. In using this, care should be taken that the sharp edge does not gouge into the tube sheet. Leaky flues can be cured sometimes by simply using the beading tool, and almost always by using the expander.

Calking.—Boilers have to be calked at the joints in order to make them steam and water tight. The operation is a very simple one and can be performed by almost anybody. It consists simply in driving the edge of the upper sheet down tightly upon the lower one. A rather heavy hammer is used for this purpose and a tool having rounded edges, whose appearance and method of operation is shown in Figure 16.

FIGURE 15.

If a boiler leaks around a rivet head or at a seam it can generally be repaired in a few minutes time by the use of the calking tool.

It is not safe to calk a boiler under steam pressure and it is also dangerous to use a wrench on any bolts or fittings that are screwed into any of the sheets or the boiler when it is under pressure. While the boiler may not explode, any of these parts may break off and cause a sudden rush of steam that is apt to scald the man who is doing the work, and everybody knows that a steam scald is a mighty bad one and something it does not pay to take chances with.

Exhaust Nozzles.—There is nothing more important about a traction engine boiler or a locomotive than the exhaust nozzle, for upon its construction and proper adjustment depends the draft and consequently the steaming ability of the boiler.

The ordinary exhaust nozzle consists of a special form of elbow fitted to the end of the exhaust pipe in such a way as to point exactly up the center of the chimney. The upper end of this elbow is provided with a bushing having an opening of the proper size for the fuel which is being burned.

Different sorts of fuel require different intensities of draft and so it is essential to have different sized exhaust nozzles. For example,

straw requires a small nozzle, because it requires a heavy draft; wood, a larger nozzle, and coal, which burns with less draft, requires the largest. It is always advisable to use the largest nozzle which will furnish the requisite amount of draft, because any reduction in the size of the opening through which the exhaust must pass causes back pressure on the engine, which subtracts an equal amount from the working pressure.

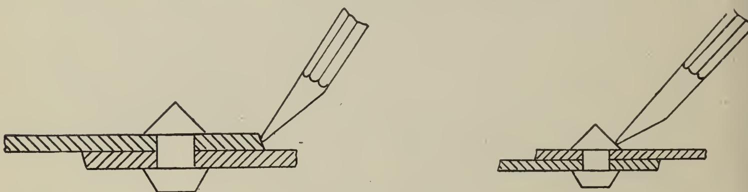


FIGURE 16.

The action of the exhaust nozzle is very simple. The rapid upward flow of steam at the base of the chimney creates a partial vacuum at that point which in turn causes some vacuum in the smoke box and in the upper part of the chimney, thus inducing a current of air to pass through the furnace and flues. If the exhaust nozzle is not pointed directly up the center of the stack the stream of steam will strike the side of the chimney and part of it will be deflected back toward the smoke-box, thus destroying the vacuum and greatly impairing the draft.

If a boiler does not steam well, one of the first things to do is to examine the exhaust nozzle and see if the proper bushing is put in for the kind of fuel used, and see that there is no lime or scale in the top of the nozzle, and make certain that it points directly up the center of the chimney. Many boilers have been condemned for not steaming well simply because the exhaust nozzle was not properly adjusted.

THE STRENGTH OF BOILERS.

Most of us have seen formulas in text books for finding the safe working pressure in cylindrical boilers, and we may have wondered where they came from and how they were obtained. It may therefore interest some of the readers to work out one of these formulas from the beginning.

In the first place, we will consider a cylindrical boiler, made up without joints or seams, that is, with the joints welded together making a seamless tube, and with the heads welded in place also. If such a boiler should burst, it is easy to show that it would be more apt to split along the side than to blow the head off. We will sup-

pose the whole boiler to be made of soft steel having a tensile strength of sixty thousand pounds per square inch. Which means that if we had a piece of such steel, one inch square, it would require a force of sixty thousand pounds to pull it apart.

Example.—Suppose we have a boiler 96 inches long, 30 inches in diameter and made of steel ¼ inch thick. If this boiler is under steam pressure, it is a well known fact that the pressure acts in every direction from the center outward, and its tendency is to separate the shell into two parts. The total force tending to pull the two halves apart will be equal to the force exerted on the flat plate *a b* of Figure 17, because the force acting upward on the curved upper half must exactly equal the pressure on the flat plate, otherwise the boiler would move, which of course it will not do. The total downward pressure on the flat plate can be easily figured. The area of this plate is 30×96=2,880 square inches. If the steam pressure is 100 pounds per square inch, the total pressure on the plate is 2,880×100=288,000 pounds. The metal holding this plate to the upper half is the metal along the edges *a* and *b*. In order for the plate to separate from the curved part the metal must tear apart at *a* and *b* throughout the entire length of the shell. The area of this metal is 2×¼×96=48 square inches. Under the given conditions 48 square inches support 288,000 pounds, consequently each square inch is subjected to 288,000÷48=6,000 pounds per square inch, or just one-tenth of what it would require to tear the metal apart.

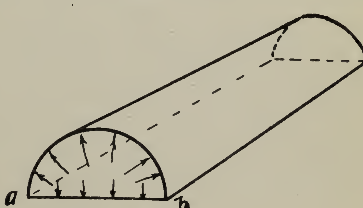


FIGURE 17.

If each square inch of metal were subjected to 60,000 pounds the total force acting on the flat plate would be 60,000×48=2,880,000 pounds, and since the area of the plate is 2,880 square inches the pressure within the boiler to cause the rupture would be 2,880,000÷2,880=1,000 pounds per square inch. We can now proceed to find a formula for finding the bursting pressure of any boiler.

Let T=60,000.

P=bursting pressure.

D=diameter of boiler in inches.

Z=length of boiler in inches.

t=thickness of boiler plate in inches.

$$\text{Then } P=\frac{60{,}000\times 2\times t\times Z}{D\times Z}$$

But since the Z appears both in the numerator and in the denominator it cancels out and our formula reduces to a simpler form as follows:

$$P = \frac{60{,}000 \times 2 \times t}{D}$$

This, remember, represents the *bursting pressure,* theoretically, of a boiler without seams or joints. Since it is usual to put in a *factor* of *safety* to find the safe working pressure we will use the factor 5, or in other words, divide the result obtained from the above formula by 5. The result obtained in using the formula for example given was 1,000 pounds, which divided by 5 gives us 200 as the safe working pressure for a boiler without joints or seams.

Putting the factor in the formula we have:

$$P = \frac{60{,}000 \times 2 \times t}{5 \times D}$$

But boilers are riveted and if the side seams are double riveted, as is the usual case, the strength of the seam is only 70 per cent of the rest of the shell, so that the safe working pressure of the above boiler with a double riveted joint is 70 per cent of 200 or 140 pounds. Inserting this factor in the formula we have: The *safe working pressure* of a cylindrical boiler, having double riveted side seams. Expressing this in a formula we have:

$$P = \frac{60{,}000 \times 2 \times t \times 70}{5 \times D \times 100}$$

Assembling all the figures and putting them in the formula,

$$\frac{60{,}000 \times 2 \times \frac{1}{4} \times 70}{5 \times 30 \times 100} = 140 \text{ pounds, safe working pressure.}$$

If the boiler is 40 inches in diameter and the thickness of the plate is the same, the safe working pressure is:

$$\frac{60{,}000 \times 2 \times \frac{1}{4} \times 70}{5 \times 40 \times 100} = 105 \text{ pounds.}$$

This shows that if we increase the diameter of the boiler it will not stand so much steam pressure, unless we increase the thickness of the boiler plate a corresponding amount. In other words, the larger the diameter of the boiler the weaker it is, with the same thickness of plate.

In the fore part of this lesson it was shown that, with 100 pounds pressure in the boiler, each square inch of metal along a side seam was subjected to a stress of 6,000 pounds. We will now consider the *stress* on a circumferential seam, that is, to prevent one of the heads from blowing out. The area of a 30-inch boiler head is $3.1416 \times 15 \times 15 = 706.86$ square inches. If the pressure is 100 pounds per square inch the total pressure on the head is $706.86 \times 100 = 70,686$ pounds. In order for the head to blow off it must tear the metal all around the boiler. The length of this strip of metal is equal to the circumference of the boiler, or $3.1416 \times 30 = 94.248$ inches. Its thickness is ¼ of an inch, and the area of the metal that must be ruptured is $94.248 \times \frac{1}{4} = 23.562$ square inches.

Dividing 70,686 by 23.562 we obtain the quotient 3,000 which represents the stress on each square inch of metal on a transverse seam, but this is only one-half what it is along a side seam; thus showing that a boiler is much more apt to fail by splitting along the side than it is to blow the end out. This also explains why side seams are double riveted and transverse seams single riveted.

Nothing has been said yet about the safe working pressure on flat plates, or on stay bolts and braces. These require separate treatment. The formulas deduced for safe working pressure are only applicable to a cylindrical boiler shell with a double riveted side seam.

We have just shown how a formula for the safe working pressure of a boiler might be developed. The formula so found was as follows:

$$P = \frac{60,000 \times 2 \times t \times 70}{5 \times d \times 100}$$

Expressing this in words we may write the following rules:

Rule I.—Multiply twice the thickness of the boiler plate expressed in inches by the ultimate tensile strength of the plate and this product by the efficiency of the joint in per cent. Divide this product by five hundred times the diameter of the boiler and the result is the safe working pressure for a *new* boiler.

There are a number of other rules that are sometimes applied to boilers, but all are based on some such considerations as those already discussed. The rule below is known as the United States rule, or, more strictly speaking, it is the rule prescribed by the Board of Supervising Inspectors of steam vessels.

Rule II.—Multiply the thickness of the shell and the ultimate tensile strength and divide by six times the radius of the boiler.

Kent in his "Mechanical Engineer's Pocket Book" gives another rule that is much more simple than either of the others but it gives results that are rather low.

Kent's Rule.—Multiply the constant number 14,000 by the thickness of the plate and divide by the diameter of the boiler in inches.

Applying these various rules to the same problem will give results that vary quite widely, depending upon the factor of safety that the investigators decided upon in working out the results.

These rules are applicable only to cylindrical boilers and can not be used in figuring the safe working pressure of boilers that have flat surfaces, because the stresses on flat plates are different from what they are on plates that are curved. The tendency of pressure on the inside of any structure is to form that structure into the shape of a sphere. If the walls of the structure are flat they are subjected to a cross bending strain as well as a tensile strain. A flat plate in a boiler must be treated as a beam under a uniform load, and supported at the ends. A complete discussion of this problem is outside of the scope of this book, but we will consider the rules used in figuring such plates and work out a problem.

Rule III.—Multiply the square of the thickness of the plate, in sixteenths of an inch, by 112 and divide this product by the square of the distance from center to center of the stay bolts. The result will be the allowable working pressure for plates seven-sixteenths of an inch and under. If the plates are more than seven-sixteenths of an inch thick use 120 in the place of 112.

Problem.—What is the safe working pressure on a fire box boiler having fire box walls three-eighths of an inch thick and the stay bolts placed five inches apart each way?

$$\textit{Solution}\text{—}\frac{6\times6\times112}{5\times5}=161. \quad \textit{Ans.}$$

($\frac{3}{8}$=6-16, hence 6 in the formula).

In applying this rule to a fire box boiler the strength of the cylindrical shell and of the fire box should be worked out as separate problems and the smaller of the two results taken as the safe working pressure of the entire boiler.

In return flue boilers where the main flue is very large it may be necessary to figure the strength of the flue to resist crushing, since it is weaker in that way than in any other.

Rule IV.—Multiply the square of the thickness of the plate by 89,000 and divide the product by the product of the length of the section and the diameter of the flue.

Problem.—Find the safe working pressure for a flue 36 inches in diameter with walls $\frac{3}{8}$ of an inch thick. Length of flue 6 feet.

$$\textit{Solution}\text{—}\frac{\frac{3}{8}\times\frac{3}{8}\times89{,}000}{6\times36}=60\text{—nearly.} \quad \textit{Ans.}$$

A tube subjected to external pressure is not as strong as if it were subjected to internal force. Where the flues are made very large as in some styles of stationary boilers it is customary to reinforce them with transverse ribs or flanges placed a short distance apart along the entire length of the flue.

The allowable working pressure on stay bolts is limited to 6,000 pounds per square inch, which gives a factor of safety of about seven for wrought iron and of more than eight for steel. For example, let us figure the size of a stay bolt that is placed in rows five inches apart both ways in a boiler that carries a steam pressure of 150 pounds per square inch.

Solution.—If the stay bolts are five inches apart each way then each bolt must support 5×5 or 25 square inches. With one hundred fifty pounds on each square inch the total pressure on each bolt will be 150×25, which equals 3,750 pounds. Since a square inch will support 6,000 pounds it follows that the area of the bolt needed will be 3,750 divided by 6,000 or .625 of an inch.

The diameter of a bolt of this area can be found by dividing by .7854 and then extracting the square root of the quotient. Performing this operation we find the diameter of the required bolt to be .89 of an inch, which is a little more than seven-eighths of an inch. The proper size to use, therefore, would be the next size larger or a fifteen-sixteenths inch bolt.

In figuring through stays to support the tube sheets above the tubes the same discussion will apply.

While the rules that have already been given are in general use and give fairly satisfactory results, it is true, nevertheless, that they apply only to new boilers. There are no rules yet devised that apply to old boilers and neither can there be. Where the boiler is old, all that can be done is to give it a cold water test and depend upon the judgment of the inspector as to the proper pressure the boiler is able to stand safely. The question thus resolves itself into one of the personal judgment of the inspector. While this is not entirely satisfactory, it is probably the best that can be done.

CHAPTER III.

BOILER FEEDERS AND SAFETY APPLIANCES.

BOILER FEEDERS.

In all industrial works where a company is under contract to furnish power or light, and it is essential that there shall be no interruptions in the service, extra power units are always installed so that in case one breaks down another is at hand to take its place. In a like manner two boiler feeders are always supplied so that if one is out of order another will be ready to take its place at a moment's notice.

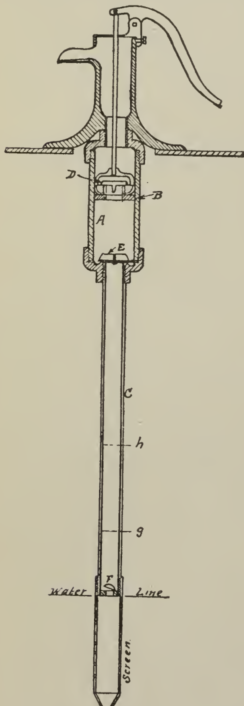


FIGURE 18.

The greatest cause of danger in handling a steam boiler comes from low water, and probably the majority of boiler explosions are due to low water, either at the time of the explosion or at some previous time, which causes a weakening of the boiler plate. Since the water supply should be under constant control at all times two boiler feeders are necessary to insure safety. Both of these should be kept in proper working order at all times. Should the engineer neglect to put the extra one in repair at the earliest opportunity it should be considered a mark of incompetency, and is sufficient cause for his dismissal without further notice. No excuse should be considered where the safety of both the crew and the machine is at stake.

It does not matter very much whether the boiler is equipped with two pumps, or two injectors, or an injector and a pump; neither does it make very much difference what make of pump or injector is used, since all standard makes are reliable and are perfectly capable of keeping the boiler supplied with water.

To understand fully the workings of pumps and injectors it will be necessary first to consider some of the natural laws governing their action.

Atmospheric Pressure.—This is the first thing to be considered in studying pumps or injectors.

The earth is surrounded by a sea of air, and everything on the surface of the earth has to sustain a portion of the weight of the air. A column of air one inch square extending from the surface of the earth, at sea level, as high as the air reaches, weighs 14.7 pounds. If we go up on a high mountain or up in a balloon, the air presses upon us with less weight because there is not so much above us. The weight of the air does not hinder us from moving because it is equal on all sides and hence all pressures are balanced.

A column of water one inch square and one foot high weighs .434 of a pound; consequently it would require a column of water 2.304 feet high to weight one pound. A column of water one inch square, in order to balance atmospheric pressure would have to be $2.304 \times 14.7 = 33.9$ feet high.

It is clear then that if all the air could be removed from the inside of a pipe which is closed at one end while the other end is submerged in water, that the pressure of the air on the outside would force water up in the pipe until the weight of water in the pipe exactly balances the air pressure on the surface of the water. If there is some air trapped above the water in the pipe, the water will rise only to such a height as is necessary to make the combined weight of water and the air pressure on top of the water equal the atmospheric pressure.

The action of an ordinary suction pump is now easily explained. In Figure 18, *A* represents the pump cylinder, *B* the plunger and *C* the pipe extending down into the water. A check valve, *D*, in the plunger opens upward and another check (*E*) at the bottom of the pump cylinder opens the same way. A check valve or foot valve, as it is generally called, is placed at *F* to prevent water from running back into the well. When the pump plunger is pushed down, valve *E* closes, valve *D* opens, and the air between the plunger and *E* escapes to the upper side of the plunger through valve *D*. When the plunger moves upwards this air is carried out and the pressure inside of the pump cylinder is reduced below that of the atmosphere; consequently the water rises to a point (*g*), where the pressure inside of the pipe exactly balances that on the outside. On the next stroke the same operation is repeated and the water rises to *h*. After a few more strokes water appears in the pump cylinder and then at the spout.

Theoretically water can be raised by a pump of this kind 33.9 feet; practically, it will only rise to a height of 24 or 25 feet, owing to imperfections in the pump and the friction of valves, etc.

While a pump of this kind is called a suction pump it does not

exert any drawing force upon the water in the suction pipe. It simply removes the air from the inside of the suction pipe and atmospheric pressure does the rest. Water rises to an injector or steam syphon in the same way. For example, in the ejector, shown in section in Figure 19, steam rushing through the tubes *A* and *B* carries whatever air there may be in the suction pipe *C* along with it, thus forming a vacuum in the ejector and its connections. Atmospheric pressure, acting at the same time, forces water up into the ejector, where it is acted upon by the jet of steam and forced out at the delivery pipe. Water may be raised by this means about twenty feet, and forced to a height proportionate to the steam pressure. An ejector is very convenient for filling the tanks of traction engines.

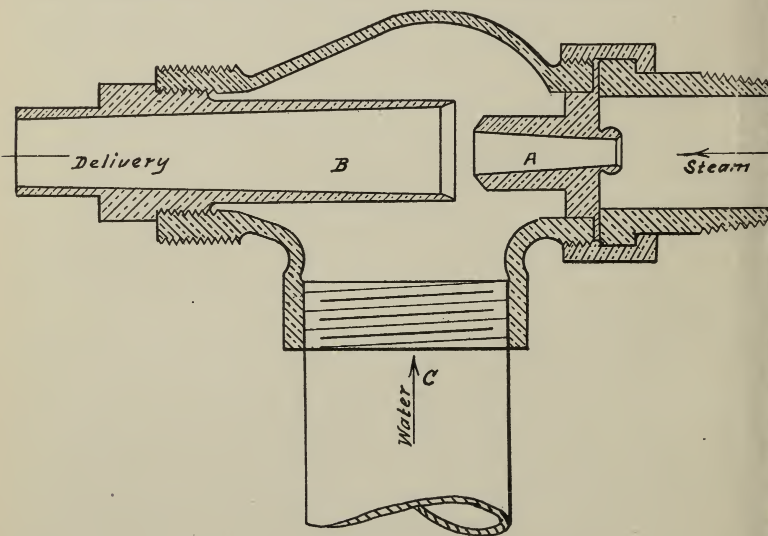


FIGURE 19.

The Injector.—There is no machine used in steam engineering that is more difficult to understand than the injector.

It seems incredible that a machine can be constructed which will take up a large quantity of water and then go back again into the boiler against the pressure from which it started. At first sight, it looks to be of the same nature as a perpetual motion machine, and it was considered in this light by the United States Patent Commissioner when it was submitted to him for letters patent. In fact, he refused, so it is said, to grant a patent until he had actually seen it in operation.

The injector, by the way, is a comparatively new machine. It was invented by Mr. Henry Jacques Giffard, a Frenchman, about the year 1857, and its manufacture was begun in this country in 1860, by Wm. Sellers & Co., of Philadelphia.

The principle of action of the injector is not easy to explain fully without the aid of some advanced mathematics; however, the following explanation will answer fairly well.

Let *B*, Figure 20, represent a cross section of a steam boiler; *C* and *D* are pipes fitted with valves which communicate with the water space and steam space respectively. We will assume a steam pressure in the boiler of 100 pounds per square inch. Now if valve *C* were opened, water would flow out with a velocity of a little more than 121 feet per second, a figure which can easily be verified by anyone having a knowledge of the laws of falling bodies.

If the valve *D* be open, with the steam pressure as before, steam will flow out with a velocity of 2,200 feet per second. We may say roughly that steam flowing from a boiler under pressure will have a velocity of from fifteen to eighteen times that of the water. This ratio changes somewhat under various conditions as to pressure in the boiler and the pressure against which the steam escapes.

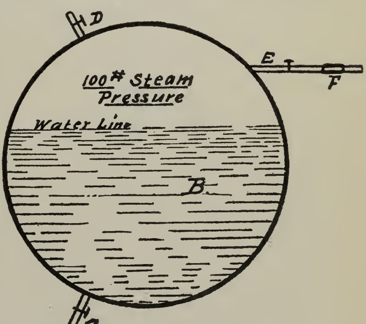


Figure 20.

If now, instead of allowing the steam to escape through an open pipe it were made to pass through a pipe *E*, having a section at *F*, that could be kept very cold so that the steam would be instantly condensed at that point, the resulting stream of water, while very much smaller than the steam in cross section, would still travel with practically the same velocity; and if this stream were directed back into the boiler it would have no trouble in entering therein, since it has a velocity about eighteen times as great as that of the water which opposes its entrance. Since this stream of water has such a high velocity it could easily carry with it a considerable extra load, and while its velocity would be reduced thereby, it would still have sufficient velocity to enter the boiler.

There are really only two types of injectors, namely, the automatic and the positive. Automatic injectors have a single set of jets, or tubes, while positive injectors have two sets. If the end of the suction hose becomes uncovered and the suction breaks, the automatic

injector will start again, but if the suction of the positive injector breaks it must be started again by hand. It is this property of the automatic injector that makes it the best form of injector for all road engines where the water washes back and forth in the tank a great deal.

Figure 21 is a sectional view of a Penberthy injector, such as is used on traction engines. When steam is first admitted to the injector, it flows through the steam jet *R,* then down through the suction jet *S,* and carries with it whatever air there is in the space between jets *R* and *S.*

This steam and air lifts the overflow valve and escapes to the atmosphere, because it has not momentum enough to enter the boiler. As soon as the air is exhausted from the inside of the injector, atmospheric pressure forces water up into the combining chamber, and condenses the jet of steam issuing from the steam jet *R.*

The chamber between *R* and *S* corresponds to the cold portion *F* in the preceding diagram, and is maintained cold so long as fresh water enters from the tank. Whatever steam there may be in the injector is now condensed by the jet of water passing through, and consequently atmospheric pressure closes the check valve *P.*

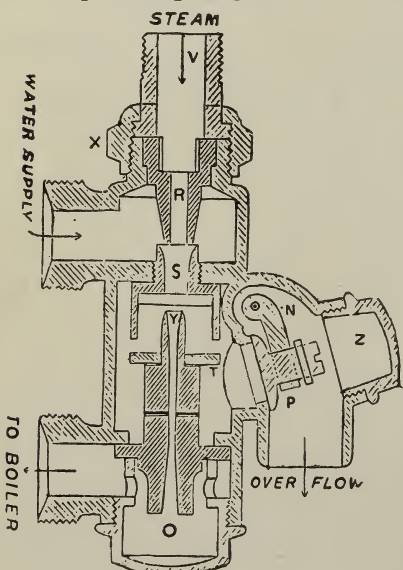


FIGURE 21.

The stream flowing through the injector must be a purely liquid one, that is, it must not contain any steam or air. If it does, the resulting stream will not have enough weight combined with its velocity to overcome boiler pressure and will consequently flow out at the overflow valve.

For the same reason, if the injector is hot, as it is if the valve in the steam pipe leaks, it will not work because some of the suction water is changed to steam by the heat in the injector and the resulting stream will contain steam. The remedy in this case is to pour cold water on the injector until it becomes cold enough to start. An injector can not handle hot water either, because hot water will not condense all of the steam.

BOILER SAFETY APPLIANCES.

There are five safety devices usually found on every steam boiler. They are a steam gauge, a safety valve, a gauge glass, a fusible plug and try cocks. All of these devices are necessary in order to make a boiler reasonably safe, and more than this, the operator or engineer should know the construction of all of these devices intimately and know how to take proper care of them so that they may be in proper working order at all times. In addition to the safety devices above mentioned, which are to be found on every traction engine boiler, there are to be found on many stationary boilers low water alarms and automatic devices which start and stop the feed pump and thus keep the water in the boiler at a constant level. These are useful, too, and serve a good purpose, but are too complicated and expensive for traction engine purposes. After all, the best safety device that any boiler can be provided with, whether it be stationary or traction, is an intelligent, well trained man to take care of it and all of its fittings. The first named safety devices may be termed essential fittings, no matter how good the engineer is, and we will proceed to study them. The steam gauge is perhaps the most important and we will consider it first.

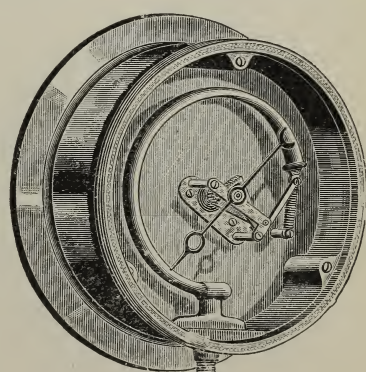


Figure 22.

The office of a steam gauge is to measure the outward pressure of the steam on the walls of the boiler. The steam gauge is a sort of weighing machine which weighs this pressure in pounds per square inch. If an accurate gauge is placed on a boiler, and it registers 150 pounds, it means that on *every square inch* inside of the boiler there is an outward pressure of 150 pounds due to the steam. The size of the opening through which steam flows on its way to the gauge is not a square inch in area, but this makes a difference since the gauge is made to register in pounds per square inch.

There are two kinds of steam gauges in common use, namely, the Bourdon spring gauge and the capsular spring gauge. Both are good gauges and both have been used for a great many years, their first appearance dating from about the year 1850. Figure 22 illustrates a Bourdon spring gauge with the dial removed showing the inside

mechanism. The spring consists of a brass tube of elliptical shape closed at the upper end and connected to the steam space in the boiler at the lower end. The outer end of this spring is connected by means of a suitable link to a segment lever whose teeth mesh with a small pinion. This pinion is mounted on a spindle which carries a pointer. When the pressure of the steam is exerted on the inside of the bent spring it tends to straighten and in doing so forces the hand around the circle and over the face of a dial. This dial is graduated and marked to show the pressure in pounds corresponding to any position of the pointer. A small flat coil spring takes up the back lash or lost motion of the pinion and makes the pointer sensitive to any changes in the Bourdon spring. The elliptical shape of these springs makes them more sensitive than if they were round. Gauges used for low pressure work are graduated up to from thirty to forty-five pounds and are fitted with a light sensitive spring. Those that are designed for high pressure work, such as for traction engines, are fitted with heavier springs and are graduated up to from two hundred to two hundred fifty pounds. Such gauges are not supposed to be accurate at low pressures below twenty-five or thirty pounds. Above that, however, they are very nearly exact up to the limit for which they are graduated.

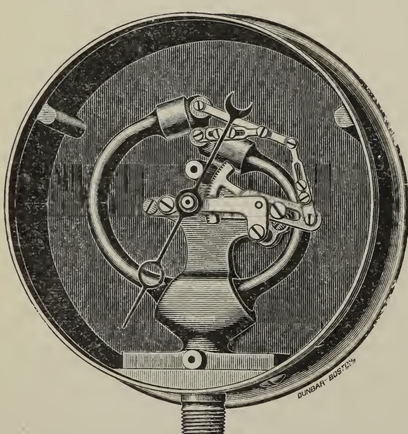


FIGURE 23.

Figure 23 shows a double spring gauge. These gauges are somewhat more expensive and are used largely on locomotives, being less sensitive to vibrations of the engine than single spring gauges and being also more substantial.

If steam were admitted directly into the Bourdon spring, the gauge would not register correctly on account of the expansion due to the heat from the steam. For this reason, and because the spring would deteriorate quite rapidly under the high temperature of the steam, a syphon is placed between the boiler and the gauge. In stationary practice this syphon often consists of a single loop of pipe, but for traction engine work a brass bulb syphon, shown in section in Figure 24, is used, the loop of pipe having too much vibration for a boiler subjected to rough road con-

ditions. The first steam that enters the syphon is condensed and a plug of water, sufficient to fill the Bourdon spring, is forced up into the gauge. Above this there is a plug of air and still below this there is steam. This mixture of air and water does not reach as high a temperature as the dry steam and does not change its temperature so quickly and is much easier on the spring. The brass syphon is arranged to drain the gauge as the steam pressure in the boiler falls.

Care should be taken to keep an accurate steam gauge on the boiler. A gauge that needs frequent coaxing with a pitchfork handle is, needless to say, not entirely satisfactory. In general, if the gauge does not agree with the pop valve, it may be considered out of order. The pop valve is much less delicate than a gauge and while it may go wrong, it is less liable to do so than the gauge. The fact that a gauge is new is not sufficient guarantee that it is accurate. While all gauges are tested at the factory where they are made they frequently get out of adjusment before getting into the user's hands. A new gauge came into the writer's hands about a year ago that was out of adjustment. The hand had slipped on its pinion. By running the pressure on the standard test gauge up to one hundred pounds and then setting the hand on the new gauge to the same point, the correct adjustment was made. A leak in the steam connections between boiler and gauge will prevent a gage from working correctly and perhaps ruin the gauge if it allows the water to escape from the spring. A cracked spring can not be mended. It is not likely to occur unless the gauge freezes and this very thing may occur and has often occurred while the boiler has been steamed up if the weather was very cold and a high wind was blowing. Under such conditions the gauge should be kept covered with a blanket or an old coat. The mechanism of a gauge rarely ever needs oiling, and if it is oiled, only a good grade of clock oil should be used and that sparingly. It is better not to use oil at all unless the engineer is very well acquainted with steam gauges.

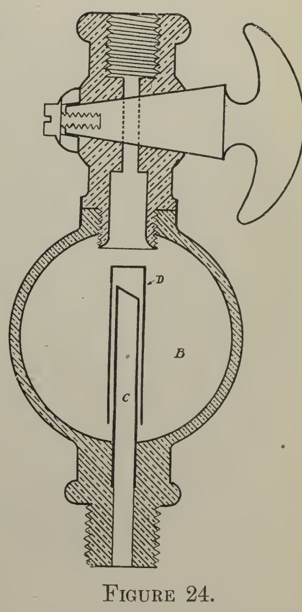


Figure 24.

Figure 25 shows a capsular spring gauge and Figure 26 shows the construction of the capsular spring. Steam pressure from the boiler forces water between the two faces of the capsular spring and spreads them apart a distance proportional to the amount of the steam pressure. This movement is transmitted through a set of multiplying levers, a segment lever and a pinion to a spindle that carries the pointer. These gauges are strong and well made and are accurate. They are not, however, used so much on traction engines as Bourdon spring gauges.

The fusible plug or soft plug is another important safety device that all or nearly all traction engine boilers are equipped with. It consists of a brass plug having an opening in the middle filled with with tin. Figure 27 shows two styles in which these plugs are made. In the one marked A, the hole in the plug is made tapering so that when steam pressure acts on the tin filling it can not possibly be forced out by the pressure alone since the pressure acts on the large end of the tin plug. In B there is an enlargement in the middle that serves the same purpose.

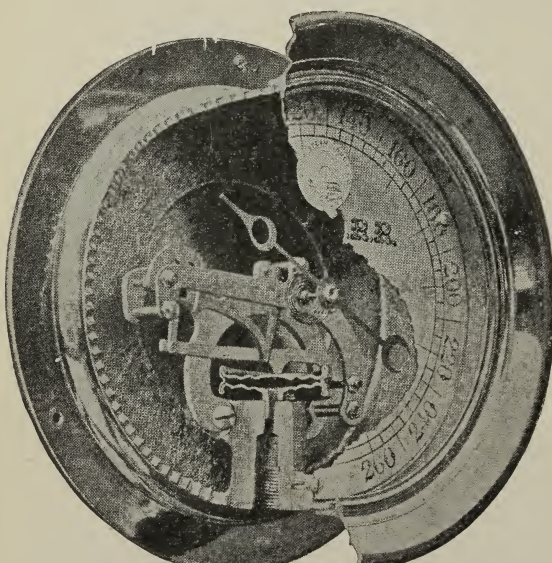


FIGURE 25.

In fire box boilers the plug is screwed into the highest point of the fire box and in return flue boilers it is located in the front end, in the smoke box, just above the main flue. The tin that it is filled with melts at a temperature of about 440° F., and if the water in the boiler gets so low as to leave the top of the plug bare, the tin melts and water and steam blow out. If this happens in a fire box boiler the fire will be put out. Many return flue boilers do not have a fusible plug, but all fire box boilers do, and they are needed.

In case a plug melts out anyone can fill it by melting a little tin in a suitable iron dish and pouring the hole in the plug full. If the plug is stood up on an iron plate it will prevent the tin from running through. After the plug is filled the tin should be tamped in with a hammer and punch. In filling be sure there is no moisture in the plug. If there is, the hot metal will turn it quickly into steam and here will be a little explosion and some one is apt to get burned with the hot tin. The plug should be filled at the beginning of every season. If left in too long it becomes crystallized and does not melt readily. It is a good plan to take the plug out every time the boiler is cleaned and see that the top is not covered with scale. A little scale on the top can easily prevent the steam from blowing out even if the tin has melted. It is also a good plan to coat the threads of the plug with graphite so that it will unscrew easily next time. Oil put on the threads will burn, forming a deposit of carbon that will make it stick and consequently oil should not be used. In concluding this bit of advice in regard to fusible plugs it may be well to add that an iron plug such as a spike is a very poor substitute for tin and is not to be recommended although some fellows who claim to be engineers use it occasionally. Babbitt is not good either although it is better than the spike. The reason babbitt is not very good is that it has a rather uncertain melting point, depending upon its composition, and may be too high. Pure tin is by all odds the best and every engine should be provided with a bar to be kept in the tool box for emergency.

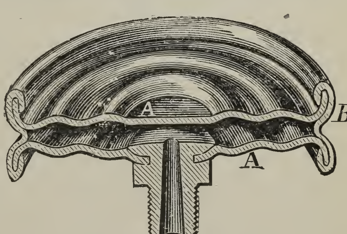


FIGURE 26.

The next safety device we will consider is the safety valve or spring pop valve, a sectional cut of one type of which appears in Figure 28. It is made of brass throughout except the springs and the handle. The lower end G screws into the steam space in the boiler and admits steam to the lower side of the main valve A. A rod B rests on the top of this valve and is held down by means of the cap H and main spring S. In order for valve A to rise it must compress the spring S. A lock nut holds the top of this spring in place and if it is screwed down it puts more load on the spring and of course more load on the top of the main valve. A full turn of this lock nut, by the way, is equivalent to adding about thirty pounds pressure on the top of the valve.

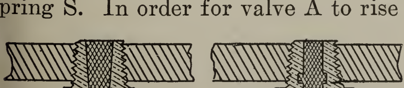


FIGURE 27.

It doesn't pay, therefore, to use a monkey wrench very freely on this lock nut unless you want to carry a tremendous pressure on the boiler. On the top of valve A there is another valve C, called an auxiliary valve. This valve is held to its seat by an auxiliary spring E. It will be noticed that this valve and spring are attached firmly to the stem of the main valve and must move with it. The purpose of this auxiliary valve will presently be described.

All pop valves are provided with what is called a pop chamber into which the steam first expands after it passes the main valve. This is shown at M, in the figure. When the pressure in the boiler is less than the compressive force on spring S, the main valve remains seated, but when it raises to a point just a trifle above the load on the spring, the valve rises and steam flows out around the valve seat V, and up into the pop chamber M, underneath the valve C. In expanding, the steam acquires considerable velocity, which is changed to pressure when stopped by the valve C. The force that now opens the main valve is the steam pressure acting on the lower side of A plus the pressure on C in the pop chamber. This total pressure is more than sufficient to open the main valve and it pops wide open. It would remain open until the steam in the boiler had fallen a considerable amount below the popping off point if there was not some provision made to relieve the pressure in the pop chamber. This is accomplished in this machine by making the compressive force on spring F much less than on spring S. This allows the valve C to lift and let the steam escape from the pop chamber. The load on spring E can be regulated by means of the nut D. If this is made heavy the pressure in the boiler will fall a considerable amount before the main valve returns to its seat. If made light, on the other hand, there will be only a

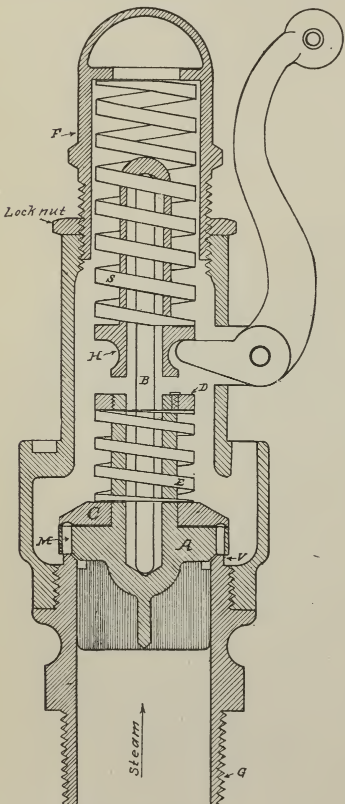


FIGURE 28.

light fall in pressure. It is set correctly when it leaves the factory and needs no further attention unless the pressure at which the main valve works is changed a great deal. In that case it may be necesary to make some adjustment.

In other types of pop valves there are different methods used to accomplish the same object that the auxiliary valve does in the pop valve above described. These devices are known as regulators and provide means for relieving the pressure in the pop chamber at varyng rates. In almost all pop valves, except the one described, this egulator must be adjusted whenever the load on the main valve is hanged very much, otherwise the pressure in the boiler will be either educed by too small an amount, or else too much pressure will be ost every time the pop valve acts. In general, the regulator should e set to reduce the pressure in the boiler about three pounds.

The pressure at which the pop valve is set on a new engine is what the manufacturer considers the safe working pressure for his boiler. While the boiler will undoubtedly be safe with somewhat higher pressures when new it is not good sense to screw down the pop and increase the pressure. As the boiler grows older it is not ble to stand such high pressures as when new and the "pop" should e set lower. It may be set down as a general rule, though not aplicable in every case, that the engineer who has a hankering to crew down the pop valve is a fellow who needs pretty close watchng. It might be safer to let him haul water.

CHAPTER IV.

FUELS AND FIRING AND BOILER HORSE POWER

FUELS AND FIRING.

Air consists of two gases, oxygen and nitrogen, mixed in proportion to one part of the former to four of the latter. Air is necessary to make a fire burn, because combustion or burning consists of the union of oxygen with the carbon and hydrogen of the fuel. Air supplies the necessary oxygen for combustion. Nitrogen does not aid combustion in the least, but rather hinders it. If nitrogen were supplied to the fire, and no oxygen, the fire would go out as quickly as though water were poured upon it.

When oxygen unites with carbon, it forms a new chemical substance called carbon dioxide, which goes out with the smoke. Smoke then, consists of the nitrogen of the air which passes through the furnace without being changed, carbon dioxide gas, some steam and some finely divided particles of soot, which is carbon that has not been burned, and which gives smoke its black color. If more air is admitted to the furnace than is necessary to supply the exact amount of oxygen for the fuel burned, then there will always be some free oxygen in the smoke, and a much larger amount of nitrogen.

Fuels.—Different fuels have different heating values. For example, a pound of coal will heat more water than a pound of wood, and a pound of wood more than a pound of straw. The heat value of a fuel is based on the amount of water it will heat and is expressed in what is called heat units.

A heat unit is the amount of heat necessary to heat one pound of water through one degree. Measured on this basis, pure carbon would, if all its heat could be utilized, raise 14,650 pounds of water one degree, Fahrenheit. In other words, one pound of pure carbon contains 14,650 heat units. Ordinary soft coal contains from 12,000 to 13,500 heat units. The following table gives the heating volume in heat units of the different fuels used in traction engines:

TABLE II.

KIND OF FUEL.	HEAT UNITS.
Good soft coal	13,500
Hard wood	8,400
Soft wood	9,000
Crude oil	20,000
Flax straw	7,500
Wheat straw	5,500

As inspection of the table shows that one pound of crude oil is equal to about 1.8 pounds of coal, and one pound of flax straw equal to one-half a pound of coal. It also shows why flax straw is so much better for fuel than wheat straw.

Duty of the Fireman.—The first duty of the fireman in the morning when he comes to the engine is to clean the flues. The tool used for this purpose should be some sort of a scraper that can be adjusted to the size of the flue by screwing the rod in or out the proper amount. The flues should be scraped clean, as a very thin coating of soot on the inside prevents heat from passing through the metal as rapidly as it should, and, consequently, it takes a long time to get up steam. As an example of the effect of soot inside the tubes, the writer, in order to prove the matter to his students, allowed an engine to run three full afternoons without cleaning the flues. The next afternoon it took hard firing from one o'clock until almost five to get up steam. On the following day the flues were cleaned and a full head of steam was gotten up in about an hour. It is often advisable to clean the flues at noon also. Of course doing o when steam is up is apt to cool the front ends of the flues and perhaps cause them to leak, but if the fire is allowed to go down rather low at first and the work is done quickly, it ought not to do any particular damage. Some boilers are fitted with a device for cleaning the flues with a blast of steam. This arrangement is a good device to use once in a while, but should not take the place f a regular flue cleaner. All the blower does is to blow out the loose oot, and does not affect the dense scale-like portion which does the eal damage, and which sticks closely to the metal.

After cleaning the flues, the next thing to do is to see if there is plenty of water in the boiler before building the fire. It is not nough to merely look to the glass, but the gauge cocks should be tried also. When the boiler is shut down for the night both the pper and lower glass connections should always be shut and the lass drained. Then in the morning it must be turned on, and when tested with the gauge cocks, there is no doubt about where the water level is in the boiler.

The next thing to do is to build the fire. If coal is used for fuel, rst start a fire with kindlings and wood. When it is going in ood shape, throw in some coal which has been broken in small ieces. It is not best to throw in very much coal at first, as it cools he fire and makes starting slower. When the first two or three hovelfuls get to going well, throw in some more, and keep on adding uel in this way until the grates are covered all over to a depth of our or five inches. This is about the proper depth of fire to carry

with soft coal in order to get the best results. It is very important that the fuel be spread evenly over the grates and that no dead or open space be allowed. Air always follows the line of least resistance and if there is a place in the grates where there is no fuel, most of the draft will go through this opening instead of going up through the fuel where the oxygen can get to the right place and aid combustion.

The result of open places in the grates is always a poor fire, and trouble in keeping up steam. For the same reason, the coal should be broken up fine—in pieces not larger than a man's fist. Large lumps of coal do not lie closely together and so make open places in the grates. It is best for the beginner to follow a system in firing; that is, throw a shovelful first in one corner, then in another, and so on around, and in that way keep an even thickness. The fire door should be opened immediately after the coal is thrown in to prevent cold air from passing into the flues. The strong draft, due to the exhaust, causes a heavy inrush of cold air every time the fire door is opened and is the principal cause of leaking flues. If the fireman is careful about opening and closing the doors, he can save the flues a great deal.

The fire should not be poked very much, but should be cleaned of ashes and clinkers occasionally, by running the slice bar down along the grates and in under the fire. What ever clinker is present should be raked out.

Care should be taken to keep ashes from piling up under the grates, because they not only obstruct the draft but cause the grate bars to burn out. If the grate bars burn it is always due to too much ashes in the ash pan, which prevent cold air from coming in below and keeping them cool.

If firing with coal there is not much danger of sparks being thrown from the stack, but with old dry wood and with straw there is danger unless the spark arrester is kept in place. In starting the fire, the spark arrester must be lifted out of the way, and may be kept lifted even after the blower is turned on, unless the fuel is very dry, but when the engine is started and the exhaust causes a heavy draft, it should be lowered in the chimney. Wire screen spark arresters should be cleaned at frequent intervals, because, like the flues, they get coated with soot, which clogs the meshes and prevents a good draft. In fact, one of the first places to look if an engine does not steam well, is at the spark arrester to see if it is dirty. If it is, the draft will be poor and the fire can not burn properly.

Firing with straw appears to be a very simple process, but in reality it is harder than firing with coal and requires constant atten-

ion, whereas a coal fire is attended to only at intervals. A man may e an expert in firing with coal and still make a failure when he ries straw. Straw requires a strong draft and plenty of air, and o if coal grates are used all but two or three should be removed—nly enough being left in place to keep whatever straw that falls nto the fire box from dropping into the ash pan. The straw chute hould be kept packed with straw at all times to prevent cold air rom passing through into the flues. Only a small forkful should be ired at a time and this should not be crowded into the fire box. The bject to be aimed at in straw firing is to keep the end of the column f straw that passes through the chute just far enough inside the ire box to burn well, but so that none of it falls onto the grates.

Straw forms a great amount of loose ash that must be raked out f the ash pit at frequent intervals or the draft will be poor. It also orms considerable hard clinker, which accumulates not only in the sh pit but also on the upper side of the brick arch. This clinker nust be cleaned out at frequent intervals also. There is also trouble rom the ends of the flues in the fire box end of direct flue boilers eing capped with soot and a sort of clinker. This must be looked fter every little while, and the caps removed with a poker through he little door in the side of the fire box that opens above the arch.

When a fireman attends to all these little things and keeps steam p and at the same time attends to the pump or injector, he is kept retty busy.

Many firemen make the mistake of firing too hard, thinking it a nark of ability to make the boiler "pop off" every few minutes. As matter of fact, it rather shows lack of ability. The steam pressure ught to be kept as high as necessary, say five or ten pounds below he popping off point. A good fireman will exert himself to keep teady pressure, because by so doing he saves fuel, saves water, and aves the boiler. A change in steam pressure means a change in emperature also, and that means either expansion or contraction f the metal and consequent wear and tear. The steam pressure can e controlled fairly well by opening or closing the drafts, by using he right amount of fuel, and by pumping in cold water at the right ime.

If the engine is fitted with a variable exhaust nozzle, this will also elp to control the steam pressure. When it gets a little too high, he relief nozzle should be opened; this will cause less draft and at he same time make the engine a little stronger by reducing the mount of back pressure in the exhaust pipe. Taking away back ressure is just the same as adding an equal amount of forward ressure.

When an engine is shut down for the evening, the fireman shoul see that plenty of water is left in the boiler. He should pump wate up above the middle gauge cock. This will reduce the steam pressur and there will not be much loss of water through the pop valve' working after the engine is shut down. The draft doors should b closed and all parts in which water accumulates during the da properly drained.

If the fireman or engineer has a system that he follows every day there is not much danger of overlooking anything. The parts tha need draining are the water glass, lubricator, pump, injector, fee pipe, cylinder, steam chest and throttle valve.

In all the Northern wheat raising states frost is apt to occu almost any night in the fall during the threshing season, and it i better to start in by draining all parts that need it the first thing i the season, and keep it up every night. There will be no danger o forgetting some cold night to open the drip cocks and no need o having to say by way of an excuse that you did not think it wa going to freeze.

HORSE POWER OF ENGINES AND BOILERS.

The term "horse power" is used more frequently, perhaps, than an other term in connection with boilers and engines. Undoubtedly most people think horse power means the same thing whether applie to an engine or a boiler. As a matter of fact, however, boiler hors power and engine horse power are quite different things.

In order to explain the two terms clearly, it will first be necessar to define work and power.

Work may be defined as the overcoming of resistance through dis tance, or as a force acting through distance. The force or resist ance is measured in pounds and the distance in feet. Work, then is expressed as the product of the two factors resistance and distance or, force and distance. The result is expressed in *foot pounds*. Fo example, if a force of one pound moves through a distance of on foot, one foot pound of work is accomplished. Or, if it requires te pounds of force to overcome a certain resistance, and this force act through a distance of twenty feet, then 10×20 or 200 foot pounds o work are done. There must always be two factors, force and dis tance, involved when work is done. Looked at in this way, work i a purely mathematical quantity.

When only one factor is involved, no work is done that can b measured. For example, a man holding a weight at arm's length i doing no work in the sense above described, because the force h

exerts does not pass through any distance. The man may get very tired and feel as though he had done a great deal of work, but according to the accepted definition of work, he has done nothing. Just as the unit for measuring distance is the foot, so the unit for measuring work is the foot pound.

Power measures the *rate* of doing work. Consequently, in all discussions of power, time must be taken into consideration, because the rate or speed at which work is accomplished is measured by the amount of time taken. Three factors enter into all considerations of power; namely, force, distance, and time. The more power an engine has, the faster it can do its work, or, the more work it can do in a given length of time, which amounts to the same thing. If two men each do the same amount of work, and the first gets through in one hour, while the second takes two hours, then the first exerts twice as much power as the second.

Horse Power.—When James Watt, the inventor of the steam engine, first put his engines on the market he found it necessary to adopt some method of measuring their power that could be readily understood and appreciated. He accordingly conceived the idea of comparing the power of his engine with that of horses. In order to do this he measured the work done by the large London dray horses, and found that on an average, they were able to do 33,000 foot pounds of work in one minute. Since that time the term "horse power" has meant the accomplishment of 33,000 foot pounds of work in one minute. Thus it will be seen that the term horse power is a perfectly definite quantity and does not depend upon what a horse may or may not be able to do. As a matter of fact, few horses can actually perform a horse power of work for a considerable length of time. Authorities on the subject state that a 1,200 pound horse, working eight hours per day, is able to accomplish only about two-thirds of a horse power of work. Larger horses, of course, can do proportionately more. For short periods of time, an ordinary horse may be able to work at a much faster rate, doing perhaps 3- or 4-horse power. An ordinary man, working eight hours per day, can do from one-eighth to one-tenth of a horse power of work.

In view of the above discussion, it will be readily seen that it is an error to say that a 25-horse power engine is equal to twenty-five horses. If the engine is actually doing 25-horse power of work, it is doing about as much as thirty-six ordinary horses. Moreover, most engines are capable of doing considerably more work than they are rated at. This is especially true of traction engines, which, by the way, are underrated a great deal. For example, the writer recently tested a 15-horse power traction engine on the brake, and found that

it easily developed 42-horse power. Even then it was not working as hard as it could, and in an hour's test no trouble was experienced in keeping up steam. As a general rule, it may be stated that traction engines are capable of developing from two to three times as much power as their rating specifies. On account of the necessity for having a large amount of reserve power to enable them to handle sudden large increases in the load, it has become the habit to underrate them much more than stationary engines. Stationary gasoline engines, on the other hand, have not generally been rated any higher than their actual capacity. Consequently, men who have replaced steam engines with gasoline engines of the same rated horse power have often been greatly disappointed in not having sufficient power. It is only fair to say, however, that at the present time gasoline traction engines are also largely underrated and compare quite favorably in actual power with steam engines of the same rating.

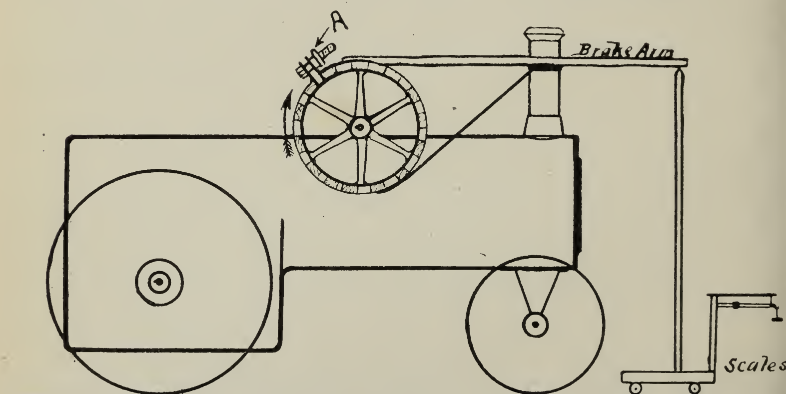


FIGURE 29.

Boiler Horse Power.—This term has an entirely different meaning from the term horse power as applied to an engine. In fact, it is more misleading than descriptive. Originally, it meant that a boiler of a certain horse power was capable of supplying steam for an engine of the same power. Later, when the engines were improved, it was found that what might be a 10-horse power boiler for one engine might be a 20- or even a 30-horse power for another. In order, therefore, to give the term a definite meaning, a committee of engineers met in Philadelphia, in 1876, and after a good deal of experimenting, decided to base the power of a boiler on the amount of water it is able to evaporate in one hour. The report of this committee stated

that a boiler horse power shall be equal to the evaporation of thirty-four and one-half pounds of water in one hour into steam at atmospheric pressure, starting with the feed water at a temperature of 212 degrees Fahrenheit. It was further specified that the boiler should work under normal conditions as to firing and that a good, ordinary grade of soft coal should be used. It will thus be seen that the term boiler horse power is quite different from engine horse power. In fact, it is not correct, strictly speaking, to say the horse power of a boiler, because a boiler does not work in the strict sense of the term. It does not overcome any resistance through a distance. It simply stores away energy in the form of steam.

The power of boilers is often based upon their heating surface, or upon the area of the grates. Ordinary multitubular stationary boilers are given twelve square feet of heating surface per boiler horse power, and one-third of a square foot of grate surface. Locomotives have about four and one-half square feet of heating surface, and only seven one-hundredths of a square foot of grate area. According to their rated horse power, direct flue traction boilers are given about eleven and a half square feet of heating surface, and forty-two hundredths of a square foot of grate area per horse power. Some builders exceed these values a slight amount, while others fall below.

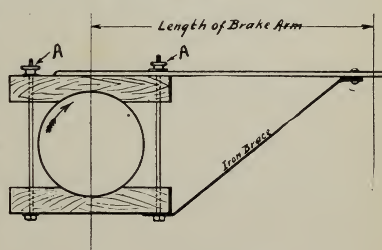


FIGURE 30.

Measuring the Horse Power of an Engine.—There are two common methods in general use for determining the horse power of an engine. In the first method a Prony brake is used, and in the second, an indicator. Brake horse power shows exactly how much work the engine is doing at the fly wheel, while the indicator shows how much work is done in the cylinder. Indicated horse power is always greater than brake horse power, because the work done in the cylinder shows the total amount of work done by the piston, and includes not only the work done at the fly wheel, but the work necessary to run the engine itself as well.

An indicator is an expensive and delicate instrument, and the services of an experienced man are required to secure satisfactory results. A brake is something that any engineer can make and is easy to operate. Figures 29 and 30 show how it may be constructed, and the following directions explain how it should be used and how the horse power is figured.

1. Place the brake on the fly wheel in the position shown, with the nuts *A* loosened so that the brake hangs free on the wheel. Now find out how much weight the brake exerts on the scales. This weight is constant and must be subtracted from all of the scale readings.

2. Oil the rim of the fly wheel, so that it will not stick to the brake, and start the engine. Now tighten nuts *A* as much as possible without slacking the speed of the engine, thus putting a load on the engine. In running it is often necessary to keep a stream of water on the wheel to keep the brake from burning.

3. Find the average speed of the engine per minute during a run of at least ten minutes, and the average load on the scales. Subtract the weight of the brake on the scale, as found in paragraph 1, and the result will be the load exerted by the engine.

4. Now measure the length of the brake arm in feet, and proceed as follows: Multiply the length of the brake arm by the average load on the scales, and by the average revolutions of the fly wheel. Then multiply this product first by 2, and then by 3.1416. Divide the final product by 33,000, and the quotient will be the brake horse power.

Example.—Suppose in a certain test, that the brake arm was seven feet long, the load on the scales 150 pounds, and the average number of revolutions 240 per minute; what is the horse power of the engine?

Solution.—$7 \times 150 \times 240 \times 2 \times 3.1416$ equals 1,583,366. This divided by 33,000 equals 47.7 horse power.—*Answer.*

CHAPTER V.

TYPES OF ENGINES, THE PLAIN SLIDE VALVE.

TYPES OF ENGINES.

There are four distinct types or classes of traction engines, namely: simple engines, duplex engines, tandem compound engines and cross compound engines.

A simple engine has only one cylinder; a duplex engine, commonly called a double simple engine, has two cylinders of *equal size* placed side by side and connected with the same crank shaft by cranks placed 90 degrees or a quarter of a turn apart. A duplex engine, therefore, consists of two separate simple engines complete in every detail.

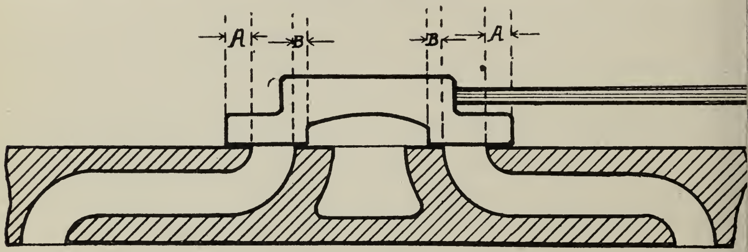
A tandem compound engine consists of two cylinders, one large, the other small, placed end to end. The small cylinder is called the high pressure cylinder, the large one the low pressure cylinder.

Steam first enters the small cylinder, and after doing its work therein is exhausted to the steam chest of the large cylinder at a much lower pressure and is then admitted to the large cylinder, where more of its energy is utilized before it is exhausted to the air.

A cross compound engine has two cylinders of unequal size, placed side by side and connected to the same crank shaft by cranks placed 90 degrees apart, just as in the double engine. The small cylinder receives the steam first and is called the high pressure cylinder. After the steam has done a certain amount of work in the small cylinder, it is passed on to the large one, where it is made to do still more work, and is finally passed out at the exhaust at a low pressure.

If the cylinder of a simple engine were eight inches in diameter, with a twelve-inch stroke, the area against which steam could act would be about fifty square inches. If steam at one hundred pounds pressure were admitted behind the piston throughout the whole stroke the total force driving it would be 50×100 or 5,000 pounds. The amount of work done per stroke by such an engine would be equal to 5,000 foot pounds, since the distance the force moves is one foot. If the engine makes 200 revolutions per minute it will make four hundred strokes, and the total work done per minute is equal to $5{,}000\times400$ or 2,000,000 foot pounds. Since 33,000 foot pounds per minute equal a horse power, the engine under consideration would develop 2,000,000 divided by 33,000 or $60\frac{2}{3}$-horse power. Such an

engine would be powerful, but it would be very wasteful of fuel an water because the steam at the end of the stroke would contain great deal of energy that goes to waste in the exhaust and does n work. The best engines do not let the steam escape until a larg part of its expansive energy has been turned into work, and conse quently when the exhaust opens the steam escapes at a low pressur



A = Outside Lap.
B = Inside Lap.

FIGURE 31.

In other words, a good engine uses the *expansive* power of the stear to perform work. In order to do this it is necessary to admit stear to the cylinder during only a portion of the stroke and then cut i off and allow it to expand behind the piston during the remainder The means taken to accomplish this desirable result are to provid a valve having *outside lap.*

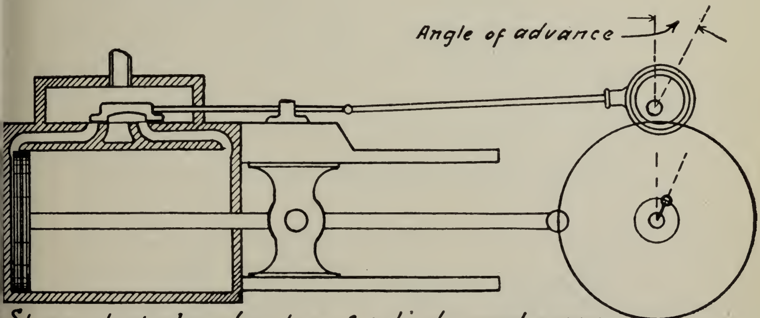
The above illustration, Figure 31, shows a valve provided wit both outside and inside lap. Outside lap governs the closing of th steam port or *cut-off,* and inside lap the closing of the exhaust por or *compression.*

If the valve were a "square valve," i. e., if it had neither outsid nor inside lap, it would take steam and also exhaust it during th full stroke. As indicated above, such an engine would not be eco nomical in the use of steam.

The position of the eccentric using a square valve is 90 degree *ahead* of the crank. If a valve having outside lap were used th throw of the eccentric would have to be larger than for a square valv in order to move the valve a distance equal to the lap, *plus* the por opening, and it would have to be placed enough more than 90 de grees ahead of the crank to move the valve at the *beginning of th stroke* a distance equal to the outside lap, *plus* the lead. The posi tion of the eccentric for this condition relative to the crank is illus trated in Figure 32. The amount the eccentric is placed ahead o

ıe 90 degrees position is called the angle of advance of the eccentric. his discussion applies to all plain slide valve engines and to link ›verse engines, but not to engines fitted with reverse gears like the Ꞁoolf reverse, or gears of that class.

After steam is cut off from the cylinder, it expands and pushes the iston to the end of the stroke, but with a constantly decreasing ressure. If the cut-off occurs very early the pressure at the end ⁚ the stroke may be almost nothing and theoretically the engine is ɔing the greatest possible amount of work with the least steam, and ›nsequently the least fuel and water. This is clearly illustrated ı the following diagrams.



Steam chest placed on top of cylinder and eccen-
·ric above shaft to show relative position of parts
o better advantage.

FIGURE 32.

The length of the diagrams represents the stroke of the engine, ıd the height of the steam pressure, both to the same scale. The ırved line shows how the pressure falls after cut-off. The whole ʒure represents the work done in the cylinder; the unshaded part, ıe work done before cut-off, and the shaded portion the work done fter cut-off. It will be observed that the work done after cut-off, · during expansion, when the steam is cut off at either one-third · one fourth stroke is more than it is before. The diagrams also ıow that at one-half cut-off, with one-half as much steam, ıeoretically eighty-six per cent as much work can be done as at ıll stroke. At one-third cut-off sixty-seven per cent as much work ın be done with one-third the steam, while at one-fourth cut-off ith one-fourth as much steam, fifty-five per cent as much work is ›complished. Herein, then, lies the secret of using steam eco-›mically.

Of course, such good economy can not be obtained practically, but practice shows that using steam expansively does result in greatly increased economy.

In addition to an early cut-off, it is also desirable to close the exhaust port before the end of the stroke so that whatever steam remains in the cylinder may be compressed. Doing this, of course

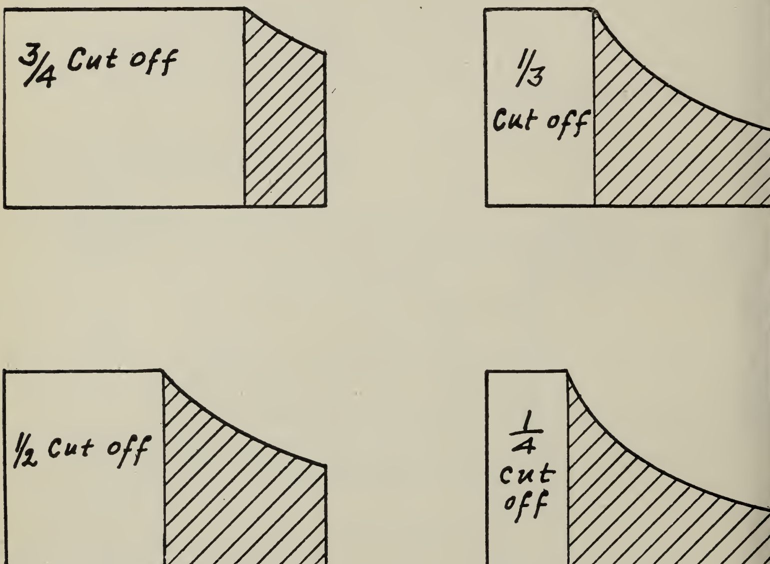


FIGURE 33.

increases the back pressure and reduces the useful work that the engine is able to do, but it is necessary to the good working of the engine for the following reasons:

In all reciprocating engines, that is, engines in which a piston works back and forth in the cylinder, the piston, piston rod, cross head and connecting rod must be stopped twice during every revolution in order to start in the opposite direction. The combined weights of these parts is between one hundred fifty and two hundred pounds in an ordinary traction engine and they travel at a rate of about five hundred feet per minute. Such a heavy mass traveling at such a high rate of speed gathers a great deal of momentum, and if the piston did not meet with considerable resistance in compressing the steam, the task of stopping these moving masses and re-

ersing their direction would come upon the crank pin. This would sult in a heavy shock not only upon the crank pin but upon the ain bearings and cross head pin, resulting in knocks or pounds at ese places and difficulty through hot bearings. If the valve is ven some inside lap, compression or cushioning of the exhaust elps bring the moving parts to rest and the stress comes upon the linder head instead of upon the bearings.

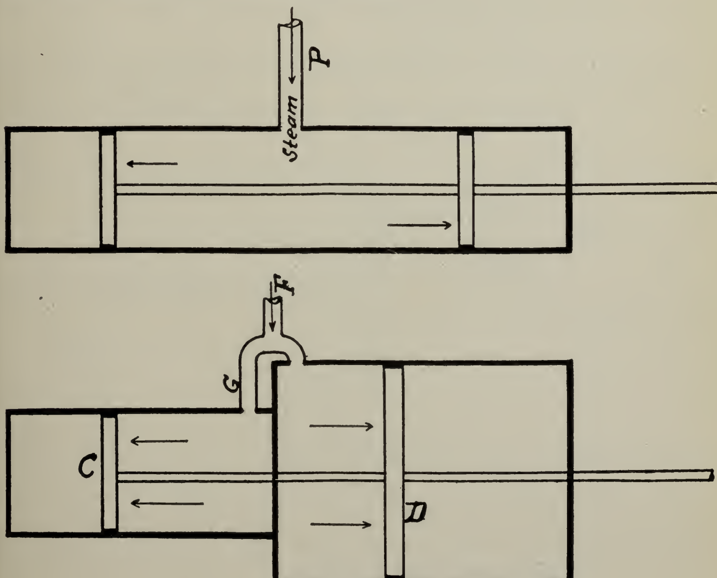


FIGURE 34.

The above discussion will explain why a badly set valve sometimes akes an engine pound at the crank pin, or main bearings, for if e valve is so set that there is no compression or cushion of the eam at one end of the stroke, the task of stopping the piston, cross ad and connecting rod falls upon the crank pin and main bearings.

The question is often asked, why are the cylinders of a compound gine of unequal size? This is easily answered by the aid of the companying diagram, Figure 34. In diagram A, two pistons of ual size are secured to the same rod and steam is admitted be- een them through pipe P. Since both pistons are of equal size the tal pressure acting toward the right is the same as that acting ward the left, and consequently there can be no motion. In figure

B, where the pistons are of different size, the pressure per square inch on the right of C, and on the left of D, is the same. The total pressure on the large piston will be greater than on the small one and consequently movement will take place in the direction of the large piston. Whatever pressure there is on the small piston, however, will act as back pressure, and it is only the pressure on the *difference* in the area that produces motion. Suppose the area of the small piston were thirty square inches and the area of the large piston were fifty square inches.

If steam at sixty pounds pressure be admitted to both cylinders through pipes F, and G, it will exert a total pressure on piston D, of 60×50 or 3,000 pounds acting toward the right and a back pressure on piston C, of 30×60 or 1,800 pounds; the effective pressure, therefore, acting toward the right on the large piston is 3,000 minus 1,800 or 1,200 pounds. If both pistons C, and D, were the same size, the steam admitted between them could not work, since the back pressure on one would exactly offset the forward pressure on the other. It must always be remembered that the forward pressure on the large cylinder is just about the same, or a little less, than the back pressure on the high pressure piston.

The economy gained in using a compound engine arises largely from the fact that greater advantage can thus be taken of the expansive power of high pressure steam than with a simple engine.

The power of an engine and its smoothness of running depend, to a great extent, upon the way the valve is set. If a plain slide valve is set with all the lead at one end, it will cut off steam earlier in one stroke and later in another, and, consequently, the engine will do more work on one stroke than on the other. This will cause the engine to use more steam than if the valve were set correctly and the power of the engine will be less. The use of more steam demands harder firing together with the use of more fuel and water. Besides, when a valve is too early on one stroke it will be too late on the other. Therefore on one stroke, compression will occur too early and on the other too late. This may cause compression to rise higher than the boiler pressure, and force the valve from its seat; then when the port opens, the steam compressed in the cylinder will escape to the steam chest and the valve will snap back on its seat, making considerable noise, while on the other stroke when there is little or no compression to take up the shock of reversing the moving parts there is apt to be a knock at the crank pin or cross head pin or in the main bearings.

In view of the preceding discussion it will be seen that much depends upon how the valve is set. Every engineer should study the

valve motion of his engine and be prepared to set it correctly in case it gets out of adjustment. The first thing to be learned is how to put an engine on dead center. An exact method of doing this with the use of a tram will now be described, step by step, and the directions should be followed in the order given.

DIRECTIONS FOR PUTTING AN ENGINE ON DEAD CENTER.

1. Take up all lost motion in the cross head, connecting rod and main bearings.

2. Turn the fly wheel until the crank stands a little above center as shown in Figure 35.

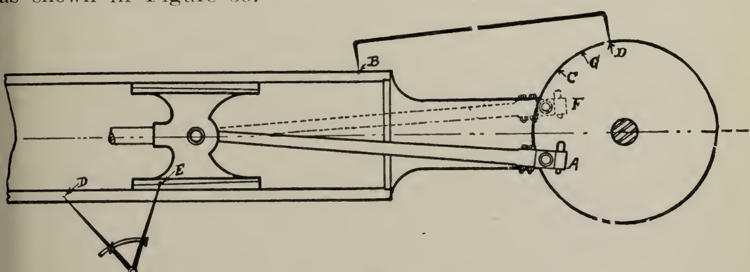


FIGURE 35.

3. Make a prick punch mark on the guides as at *A*, and another on the cross head *B*. Set a pair of dividers so that the points will fit into these two marks.

4. Make a prick punch mark on some convenient part of the frame as at *C*. Now, with one end of the tram *D*, in *C*, mark a point on the rim of the fly wheel or crank disc. Call this mark *E*.

5. Now turn the crank below the center, as shown by the dotted lines, until the point *B*, will come back to its original place and the points of the dividers will again fit into the two marks, *A* and *B*. The crank is just as far below center now as it previously was above center.

6. With one end of the tram in *C*, find another mark F, on the crank disc.

7. Now find a point *G* exactly midway between *E* and *F* and mark this with a prick punch.

8. Turn the crank in the direction the engine is to run until the tram will fit into the two marks *C* and *G*. The engine is now on dead center. The other dead center can be found in exactly the same way.

After the marks are once established, with the same tram the engine can be quickly put on dead center again. It is a good plan for an engineer to make up a tram of stiff wire and find the proper marks *C,* and *G,* as described above, and then lay his tram away in the tool box so that he can put his engine on dead center at a moment's notice, thus being prepared to set the valve quickly in case it becomes necessary.

PISTON CLEARANCE.

1. Put engine on dead center and scribe a mark across cross head and guides. Call this line A.
2. Put engine on other dead center and scribe another mark. Call this line B.
3. Disconnect connecting rod from crank.
4. Open the cylinder and push piston to extreme head end of cylinder, and measure from line A on guide to line A on cross head.
5. Push piston to crank end of cylinder and measure from line B on guide to line B on cross head.
6. If the measurements do not agree, either lengthen or shorten the piston rod where it enters the cross head, one-half the difference in the measurements.

Another way to make sure of clearance is as follows: Put engine on dead center, disconnect the piston rod from the cross head, and push the piston to the extreme end of stroke. Now connect piston to cross head, and shorten the piston rod one-eighth of an inch; this will provide an eighth of an inch clearance at one end and will leave a little more or less than that amount at the other. At any rate there is no danger of the piston's striking the cylinder head.

DIRECTIONS FOR SETTING A PLAIN SLIDE VALVE.

The following directions refer to a plain slide valve engine without a reverse gear, and should be followed in the order given to insure success.

1. Take up all lost motion as described for putting an engine on center, and then take off the steam chest cover.
2. Turn the engine over by hand, and observe if the valve opens both the right hand and the left hand ports the same moment. If it does not do so, adjust it on its stem until it does.
3. Place the engine on dead center and then rotate the eccentric on the shaft in the direction the engine should run, starting from a position opposite to the crank, until the valve shows the proper lead on the side nearest the piston.

4. Secure the eccentric in this position by means of the set screws and turn the engine to the other dead center. The valve should have exactly the same lead, and it will have if the adjustment in item 2 was made *correctly.*

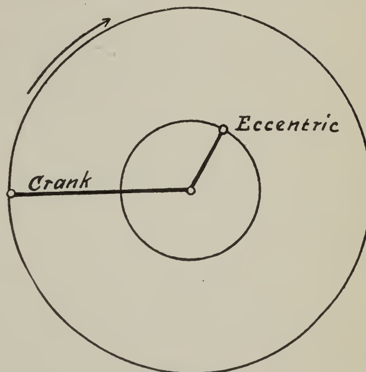


FIGURE 36.

5. In case the lead is not the same, correct half of the *error* by moving the eccentric, and the other half by moving the valve on its stem. The valve will now be set correctly. The lead can either be increased or decreased an equal amount on both sides by moving the eccentric on the shaft. Moving the valve on its stem has the effect of increasing the lead on one side and of decreasing it an equal amount on the other. The amount of lead that should be given differs with different engines, and no general rule can be laid down that will be of any value. Some engines, even of the same make, require more lead than others. The best thing to do if the engine does not run smoothly is to make several trials until the correct lead is found for that particular engine.

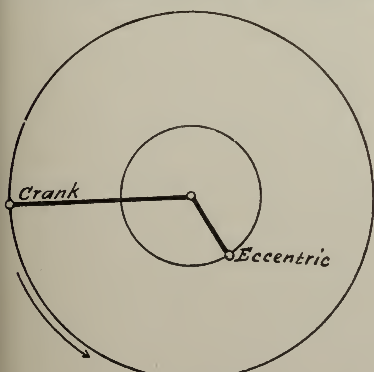


FIGURE 37.

The correct position for the eccentric, relative to the crank, is shown in Figure 36, and the direction of rotation of the engine is shown by the arrow. In order to reverse an engine of this kind, the eccentric must be placed as many degrees *ahead* of the crank in the *opposite* direction, as shown in Figure 37. These directions, it must be understood, apply only to a slide valve engine whose eccentric rod attaches directly to the valve stem without the intervention of a rocker arm. The position of the eccentric for the Woolf valve gear and the other reversing gears of a similar type, is entirely different and will be discussed on a subsequent page.

EFFECT OF THE ANGULARITY OF THE CONNECTING ROD.

The crank end of the connecting rod moves up and down past the center line of the engine during every revolution an amount equal to the length of the crank. This affects both the motion of the piston and the action of the valve in the following manner.

In Figure 38, *A-B,* represents the stroke of the piston. For convenience, the connecting rod is supposed to be connected directly to the piston, thus dispensing with a cross head or piston rod. The point *C,* is midway between *A* and *B.* Now with a pair of dividers set equal to the length of the connecting rod, set one leg at *C,* and strike an arc across the crank circle, cutting the latter at *D.* This shows that when the piston has reached the mid point of its stroke that the crank has not made a quarter turn. When the piston travels from *C* to *B,* however, the crank will be at *E.* Therefore, during the first half of the piston stroke the crank does not travel as far as it does during the last half. This is due to the angle made by the connecting rod with the center line of the engine.

In all well governed engines the crank travels at a uniform rate of speed, that is, it takes the same time in making the first quarter of a turn that it does the second, therefore the piston must travel faster during the first quarter of a revolution of the crank than it does during the second quarter, starting from the head end of the cylinder. Now since the valve is driven from the shaft, it must keep exact time with the crank, but since the piston does not travel through equal distances for each quarter turn of the crank, it is evident that the valve and piston do not keep time with each other.

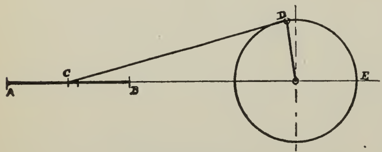


FIGURE 38.

If the valve cuts off steam at a certain point in the stroke on the forward motion, it will not cut off steam at the same point in the stroke on the return motion, a result due to the disturbing action of the angularity of the connecting rod. Consequently, in an engine such as we have been discussing, it is impossible to set the valve with equal lead and have equal cut-off. By making the lead unequal it is possible to make the cut-off equal for both the forward and return strokes, but this is seldom done in practice. The usual method, and in general the best satisfaction, will be obtained by setting the valve with equal lead even if the cut-off is not equal.

Link reverse engines and reversible engines having a slotted eccentric, are affected in the same way as plain slide valves by the angularity of the connecting rod. There are some reversible engines, however, in which this difficulty is overcome.

CHAPTER VI.

TRACTION ENGINE REVERSING GEARS.

REVERSING GEARS.

When one looks over the various traction engine catalogues and reads the descriptions of each of the valve and reversing gears described therein, he is apt to think, unless he is especially observing, that each designer has succeeded in finding something entirely different from any of his competitors. Such, however, is not the case, as we will attempt to show. As a matter of fact, there are only three different principles involved in all traction engine reverse gears, consequently we may divide all gears into the three following classes:

1. The link reverse, using two eccentrics.
2. The radial reverse, using one eccentric.
3. The shifting eccentric reverse gear, with one eccentric.

There are many modifications of each of these three classes, but, as before stated, all traction engine reverse gears fall into one or another of these classes. They will now be taken up and discussed in the order just given.

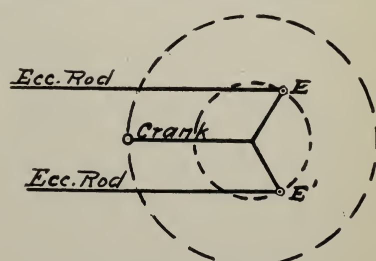


Figure 39.

The Link Reverse is provided with two eccentrics, one set about 120 degrees ahead of the crank, the other just as far behind, as shown in Fig. 39. If these two eccentrics are so arranged that either one can be made to drive the valve it is evident the engine can be reversed. With the crank in the position shown, the piston must be at the left end of the cylinder, and for the engine to run the left steam port must open. If the eccentric rod were fastened to the upper eccentric *E,* the crank must move upward to pull the valve toward the right. On the other hand, if the eccentric rod were fastened to *E* , the crank must move downward to pull the valve toward the right. We could reverse an engine with two eccentrics set in this way by detaching the eccentric rod from one and fastening it to the other eccentric, but the device would be very awkward and it would be necessary to stop the engine each time we wanted to reverse it. To get around this difficulty a curved link is used provided with block *B,*

Figure 40, which is free to slide in the link. The two eccentrics are attached to the link as shown, and the valve stem is fastened to the block *B*. The link is suspended from its center by means of a strap *S*, attached to the bell crank lever *L*. The latter is pivoted at *P* to some point on the engine frame. Connection between the bell crank lever and the reverse lever *R* is made through the rod *D*. When the reverse lever is in the center notch of the quadrant, as shown in the drawing, the block *B* is in the center of the link. If the reverse lever is pushed forward to notch *e* the link will be raised and the block *B* will be in the lower part of the link opposite eccentric *E′*. In this position the other eccentric will have practically no effect upon the movement of the valve at all and so the throw of the valve and the direction of rotation of the engine will depend entirely upon

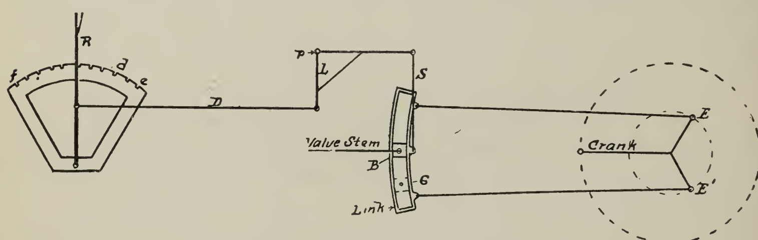


FIGURE 40.

eccentric *E′*. If the reverse lever be made to occupy position *f*, the link will be pushed down and eccentric *E* will control the valve and the engine will be reversed. If the reverse lever is in the middle notch, the link will merely rock back and forth under the action of the two eccentrics and since the block is in the middle of the link it will have almost no movement and the valve will remain practically stationary. However, if the reverse lever be shifted to *d* so that the block occupies position *G*, the valve will be under the influence of both eccentrics, but since it is nearer to *E′* than to *E*, the former will give the engine its direction. The effect on the valve will be to shorten its travel, provide less port opening and cause cut-off to occur earlier in the stroke. By providing the reverse quadrant with the proper notches, cut-off can be made to occur at any place in the stroke from almost nothing up to the maximum for which the reverse gear is designed.

It will thus be seen that the link reverse not only provides a means for reversing the motion of the engine, but also controls, to a large extent, the distribution of steam to the cylinder.

Stephenson, the inventor of the locomotive, invented the style of ink reverse used on traction engines. It is said that all he aimed o do was to design something that would merely reverse the engine, ut after the link was put in operation it was discovered that it could e hooked up and thus control the cut-off of the steam as well. This nakes it very valuable on locomotives, because the engineer can save team by hooking up whenever he comes to an easy grade. It also nables him to govern the speed of the engine by cutting off the team a little early and thus reduce the average pressure on the pis-on. The angularity of the connecting rod affects the valve motion n just about the same way as for a simple engine.

The Radial Reverse Gear.—In this type of gear the eccentric sheave s fitted with a long strap to which the eccentric or valve rod is at-ached. The outer end of this strap is compelled to travel in a fixed ath either by means of a guide or by means of a radius link.

There are several styles of radial gears applied to traction engines, ut the one which is most familiar is the Woolf reverse.

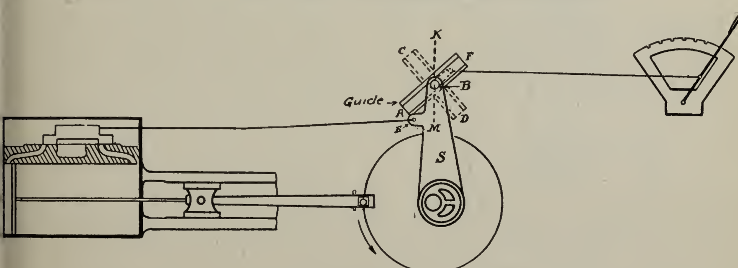


FIGURE 41.

A diagram showing the principles of this gear appears in Figure 41. The eccentric is set just opposite to the crank, and the valve rod is ttached to the strap *S*, at *E*. The upper end of the strap is pro-ided with a guide block or roller which moves along an inclined uide. This guide may be tilted, either in the direction of *AF* or *D*. When in the position *AF* the engine must run in the direction f the arrow. When the guide is tilted in the direction *CD* the en-ine is reversed. When the engine is on dead center the valve shows certain amount of lead. The center of the guide block *B* is oppo-ite the pivot on which the guide turns, so that moving the reverse ever does not move the valve. Referring to the figure it will be seen hat if the crank is rotated in the direction of the arrow the block *B* vill move upward along the guide *AF*, and toward the right, thus

pulling the valve toward the right and opening the left port. If the crank were moved up and the guide left the same, the valve would close the port and the engine could not run.

Practically the same direction could be given to the strap *S*, if it were connected up with a radius link as shown in Figure 42, instead of with a block and guide. If the link be pivoted at 1, the end of the strap must move along the line *AF*, and if pivoted at 2, along the line *CD*. These two arcs, it will be noted, correspond to the directions of the guide in Figure 32. When pivoted at 3 the arc *KM* will correspond in general direction to the vertical position *KM*, of the guide in Figure 41. This is the direction the end of the strap will take when the reverse lever is in the center notch in either case. When the point *B* moves along the line *KM* the valve will have practically no movement. If an engine with a gear of this kind has the reverse lever placed in the center notch it may keep on running, if it is not loaded. It will net get steam enough to do any work, however, if the valve is set right. If the guide in Figure 41 is tilted a slight amount from the position *KM*, the valve will be given only a little movement and cut-off will occur early. Or, if the point *P* in Figure 42 be made to occupy positions *a*, *b* or *c* the valve will have a smaller movement than when it is at 1 or 2 and cut-off will occur earlier. It is clear, therefore, that with a radial valve gear an engine may be hooked up as much as may be desired. Some of these gears are arranged to give an equal cut-off on either the forward or backward stroke. All of them do better in this respect than the link reverse. They all provide for an equal lead on both strokes. The lead, furthermore, is constant, that is, it is the same for all cut-offs, while the lead of the link reverse either increases or decreases as the engine is hooked up, depending upon the way the eccentrics are set.

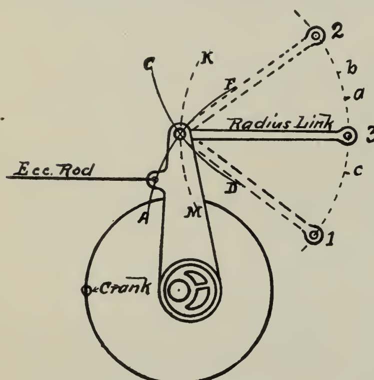


FIGURE 42.

The radial gear is very susceptible to lost motion. If not adjusted correctly and lost motion exists, the radial reverse does not give very good distribution of the steam to the cylinder. In this respect it does not give quite as good results as the link. However, they are

›th good reverses, and since both the good and the bad points of both ıve been presented, the reader may judge for himself between them.

Shifting Eccentric Reverse Gears.—The eccentric in this type of ›ar is usually made in the form of a ring through which the main ıaft passes. This ring is provided with planed guides on one side hich are free to slide in ways attached to a hub which is secured to ıe shaft by means of a set screw. Motion is given to the eccentric r various means, such as with a rack and pinion, toggle levers or vo racks having teeth cut at an ngle of 45 degrees.

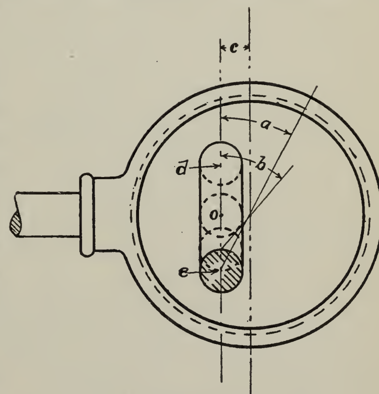


FIGURE 43.

Reverse gears of this type are ıade in two styles, illustrated iagrammatically in Figures 43 nd 44. In Figure 43 the eccentric ; made to slide straight across ıe shaft, thus changing its potion with relation to the shaft. n Figure 44 the eccentric rotates ightly about the shaft on a ›nter at *p*, and in this way its osition relatively to the shaft ; changed.

In Figure 43 it will be observed ıat the center of the eccentric ; set to one side of the center the main shaft, a distance represented by *c* in the diagram. This istance is made equal to the lap plus the lead of the valve. The rank is supposed to be at the left of the figure and the engine on dead center. When the eccentric is lifted to its extreme upper position, the shaft is at *e* and the crank will move in the same direction as the hands of a watch. If the eccentric is dropped clear down until the shaft is at *d*, the eccentric will be in position to reverse the engine. When the shaft is either at *d* or *e*, or, to be more exact, when the eccentric is shifted up or down to its extreme position, the valve will ave its greatest movement and steam will be cut off at the latest oint in the stroke. In full gear, either forward or back, the travel

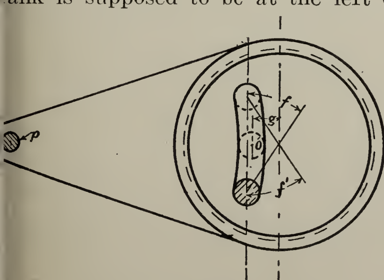


FIGURE 44.

of the valve from mid position is equal to the distance from the center of the shaft to the center of the eccentric. When the shaft is at *e*, the angle of advance of the eccentric is *a*, but when the eccentric is dropped down so that the shaft occupies the position of the first dotted circle above *e* the angle of advance has increased to *b*. As the reverse gear is hooked up, therefore, it is clear that the angle of advance increases. Also the distance from the center of the shaft to the center of the eccentric decreases, and consequently the travel of the valve becomes less. The effect of increasing the angle of advance is to make cut-off occur earlier, consequently when this valve gear is hooked up the travel of the valve is shortened and cut-off is made to occur earlier. When the reverse lever is placed in the center notch, the eccentric is dropped down until the shaft is at *o;* here the throw of the eccentric is just equal to the lap plus the lead equal to *c* in the figure. If an engine with this sort of a reversing gear is running light it will keep on running when the reverse lever is in the center notch because the valve is allowed to open the ports the amount of the lead and admit some steam. Cut-off can not be made to occur at the same point in both forward and back strokes because of the angularity of the connecting rod. The lead, however, is practically the same for all positions of the reverse lever, no matter which way the engine is running, because the eccentric is shifted acros the shaft in a *straight line.*

In Figure 44 the eccentric is pivoted at *p* to a disc which revolves with the shaft, and the path taken by the center of the eccentric when shifted either to one extreme position or the other is the arc of a circle having *p* as a center. The position of the crank in this diagram is toward the left and the engine is supposed to be on dead center. When the eccentric is in the extreme upper position as shown in the figure the angle of advance is *f* and the engine is in full gear forward. As the eccentric is dropped down nearer to mid position the angle of advance becomes greater just as in the other reverse gear previously described and cut-off occurs earlier. On account of the curved path taken by the center of the eccentric it follows that as the center of the eccentric approaches nearer the center of the shaft, as it does when the engine is hooked up, the lead decreases, and when the

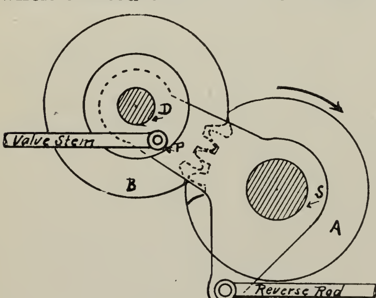


FIGURE 45.

reverse lever is dropped down the lead increases. The valve may have the same lead on either the forward or backward motion, but it can not have the same lead at all points of cut-off.

The Gear Reverse is illustrated in Figures 45, 46 and 47. Referring to the figures, *S* is the main shaft, *A* is the spur gear attached thereto and B another spur gear of exactly the same size meshing with *A*. A gear box *G* is pivoted on the main shaft and carries the gear *B* and the crank disc *C*. The valve stem is attached to this disc by means of pin *P*. When the main shaft revolves the gear *A* causes both the gear *B* and the crank disc *C* to revolve. In this way motion is given to the valve by means of a crank instead of an eccentric. Since an eccentric is only an enclosed crank it follows that the motion imparted by the crank will be no different from that given by an eccentric having the same throw. Figure 45 shows the position of this gear when running in the belt, Figure 46, when the reverse lever is in the middle notch, and Figure 47 when the engine is reversed.

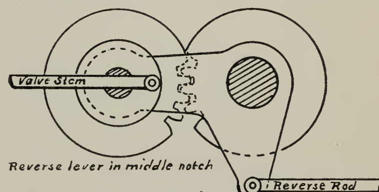


FIGURE 46.

At first sight it does not seem as though this type of reverse gear belonged to any of the classes just described, but a little consideration will show that the effect of this arrangement is identical with that we would have with an eccentric that is arranged to rotate around the shaft. Considered in this way, it clearly comes under the head of shifting eccentric gears.

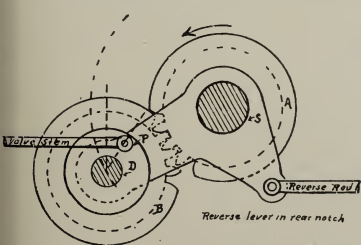


FIGURE 47.

As shown in the diagrams, there are only three positions for the eccentric, namely, full gear forward, full gear backward and mid gear. In other words, a reverse gear of this type can not be hooked up, but must take steam during whatever part of the stroke it is designed for.

CHAPTER VII.

DIRECTIONS FOR VALVE SETTING.

Directions for Setting the Woolf Reverse.—In setting this valve gear, just as in setting any of the others, the first thing to do is to take up all lost motion in the cross head, connecting rod and main bearings, as well as in the eccentric, eccentric strap and all the valve connections. Then find both dead center points so that the engine can be placed first on one dead center, then on the other by means of the tram. Place the engine on either dead center, then, if there is no indirect rocker shaft between the valve and eccentric so that the eccentric rod moves in the same direction as the valve, the eccentric should be placed 180 degrees, or half of a circle, away from the crank. If an indirect rocker shaft is used so that the valve travels in the opposite direction from the eccentric rod, then the eccentric must be placed on the same side of the shaft as the crank, or just exactly opposite to what it would be if either no rocker shaft or else a direct rocker shaft were used.

The effect of an indirect rocker shaft with any valve gear is to place the eccentric exactly half way around the shaft from where it would be without such a shaft. This may be illustrated by the diagrams shown in Figure 48. The upper diagram shows an ordinary plain slide valve non-reversible engine fitted with a direct rocker shaft. An inspection of the figure shows that the valve and eccentric rod both travel in the same direction, the only effect of the rocker being to increase the travel of the valve. The eccentric is placed a little more than a quarter of a turn ahead of the crank, just as if no rocker shaft were used. In the lower diagram an indirect rocker shaft is shown. Here the valve travels in the opposite direction to the eccentric rod, consequently in order that the engine may still run in the same direction the eccentric must be placed as shown, that is, just 180 degrees from the first position shown in the upper diagram. What is true in this regard for a plain slide valve engine is also true for the Woolf reverse when an indirect rocker is used, that is, it changes the position of the eccentric exactly half way around the shaft. In the plain slide valve engine without a rocker shaft, the correct position for the eccentric is a little more than a quarter of a turn ahead of the crank, but with an engine fitted with a Woolf reverse, the proper place for the eccentric is 180 degrees

from the crank if no rocker is used or exactly with the crank if an indirect rocker shaft is interposed. After the eccentric is placed in what appears to be the correct position, as near as can be judged by the eye, reverse the engine and note if doing so moves the valve. If it does, shift the eccentric one way or the other a little until a position is found where reversing the engine will not move the valve. When this point is found, shift the valve on its stem until it has say one-sixteenth of an inch lead. Now place the engine on the other dead center and see if the lead is the same; if not, corrrect half of

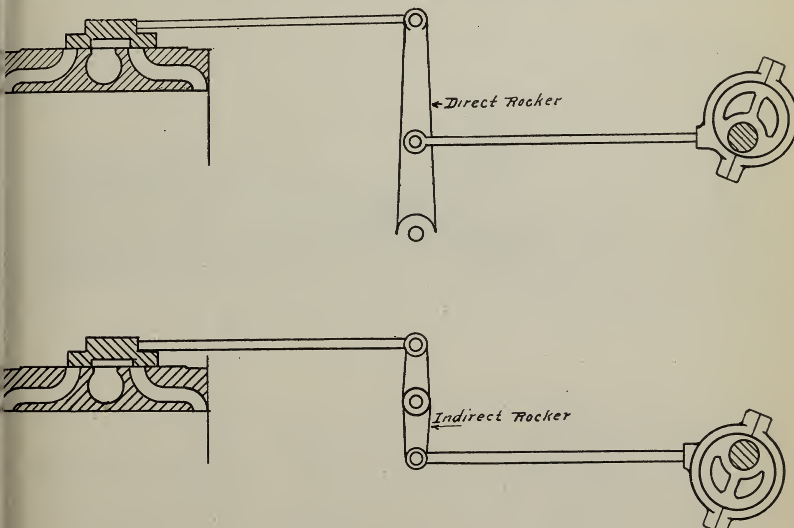


FIGURE 48.

the error and the valve is set. With a valve gear of this kind it is impossible to give the valve either more or less lead and still have it equal on both dead centers. When the lead is made equal the valve is correctly set on its stem and it will have just the amount of lead the designer intended. In the case of the ordinary plain slide valve the lead may be either increased or decreased by shifting the eccentric; with the Woolf reverse the lead may be equalized, but it can not be changed from what it was designed to be.

Some of the Woolf valves are so designed that there will be a slight movement of the valve, even if the eccentric is correctly set, when the engine is on dead center and the reverse lever is worked back and forth. A point can be found for the eccentric, however, where the

movement will be the least, and this is its correct position. If the pivot on which the guide block rotates (see Figure 49) is exactly in line with the center of the pivot by which the block is attached to the eccentric strap, then when the engine is on dead center, reversing the engine will have no effect upon the valve, unless the engine is moved off from center.

The Woolf valve and all valves of its class provide for a constant lead for all positions of cut-off, on either the forward or backward movement, and provides for a much quicker opening of the port

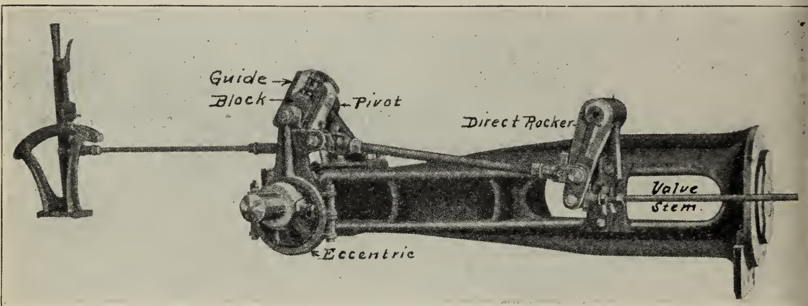


FIGURE 49.

than a valve moved simply by means of an eccentric, such as, for example, a plain slide valve or a link reverse engine. It has been, and is yet, used widely on traction engines on account of its simplicity and the fact that there is only one eccentric to set in case of trouble, and because it is easy to put in correct adjustment in case it gets out of order.

It is not, however, a perfect valve gear, although when correctly designed it gives good distribution of the steam and provides for as many points of cut-off as there are notches in the reverse quadrant. It is very susceptible to lost motion in any of its connections, a small amount being sufficient to account for a poor distribution of the steam. In this respect it is more sensitive than the link or a slotted eccentric valve gear.

Owing to certain peculiarities in construction, the Woolf valve gear can not be made to work exactly the same on both motions of the engine, although when special care is taken in the design, the difference can be reduced to a small amount. It will generally be found, however, on examining valves of this kind, that they have a longer travel when the engine is running in one direction than when the

engine is reversed. This difference may be reduced by making the reverse rod of such length that the guide for the block stands at a steeper angle on one motion of the engine than on the other.

After an engine has been used for two or three years, the main bearing is apt to be worn down so that the shaft is slightly lower than when it was first put in place. This brings the center of the block slightly lower than the center of the guide and affects the steam distribution adversely. When this trouble arises the engine should be re-aligned, and the main shaft raised to correct height, and new boxes poured.

In the case of Woolf compound engines fitted with a single valve, all that need be considered in setting the valve is the large central part which admits steam to the low pressure cylinder. If this is given the correct lead the high pressure valve must be set right, if it is designed correctly, because both the low pressure and high pressure valves are cast together.

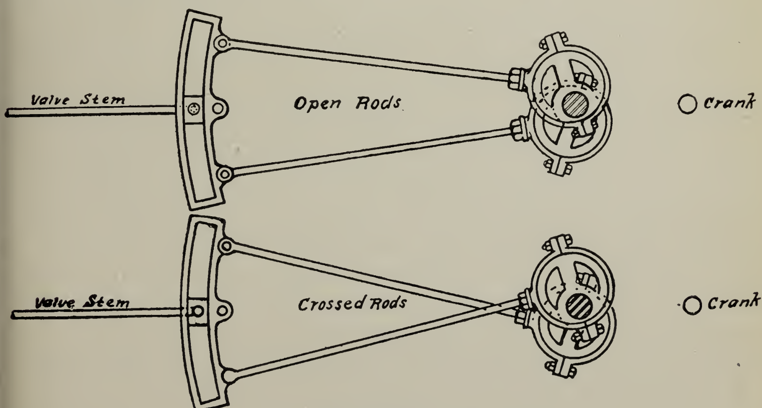


FIGURE 50.

It may be mentioned in passing that the term "Woolf compound engine" does not necessarily imply that the engine is fitted with a Woolf reversing gear. A Woolf engine is one having two cylinders with a common cylinder head between them. Such an engine may or may not have a Woolf valve and reversing gear.

The eccentric rods of a link reverse engine are frequently spoken of as being either *open* or *crossed.* Since the rods are always crossed either on one dead center or the other, the term needs to be defined. By common consent among engineers the rods are said to be *crossed* if they cross each other when the engine is on dead center, and both

eccentrics are pointing *toward the link.* If the rods are parallel when the eccentrics point toward the link the rods are said to be *open.* The two conditions are clearly represented in Figure 50, the upper diagram showing open rods and the lower crossed rods.

Traction engines having a link reversing gear have the rods set *crossed* usually, but they may be set with the rods *open* if desired. "Hooking up," that is, moving the reverse lever nearer to the center notch, *increases* the lead if open rods are used and *decreases* the lead when crossed rods are employed. Consequently, putting the reverse lever in the middle notch will stop an engine having crossed rods, but if open rods are used the engine will not stop, ordinarily, when running light, because the valve opens the ports a considerable amount at the end of the stroke, thus admitting a considerable quantity of steam which expands behind the piston and pushes it forward.

Directions for Setting the Link Valve.—Two accidents are liable to happen in the field, either the valve may slip on its stem or one or both of the eccentrics may slip on the shaft. To determine just what is the matter, first put the engine on dead center, according to the directions already given and note if the eccentrics appear to be placed as they appear in Figure 50. If they are so placed they are probably all right. The next thing to do is to remove the steam chest cover and observe the position of the valve. If it has slipped, the fact can generally be determined by the old grease marks on the valve stem. All that is necessary to do in this case is to throw the reverse lever over to one end of the quadrant and shift the valve until it shows the proper lead on the side nearest to the piston. If it is impossible to tell by the grease marks if the valve has slipped, look to the lead, then put the engine on the other center, leaving the reverse lever in the last notch of the quadrant in both cases, and see if the lead is the same; if not, the valve has slipped and it should be moved on its stem an amount equal to half of the error.

To test if the eccentrics have slipped, throw the reverse lever over to one end of the quadrant and then put the engine on dead center. Now observe the lead and then put the engine on the other center. If the lead is the same, but either too much or too little, it shows that the eccentric in line with the valve stem has slipped. It should be moved in the right direction to make the lead right and the set screw set down to hold it in place. When the first eccentric is set in this way reverse the engine and repeat the operation for the other eccentric.

In case one of the eccentrics becomes broken, or something happens, making it necessary to put in new rods, the operation is a little more

difficult because the rods must be adjusted to the right length. This operation may be performed as follows:

Throw the reverse lever over to one end of the quadrant so that the valve will have full travel, then connect up both eccentric rods making them as nearly equal in length as possible by eye. Now put the engine on the crank end dead center, and rotate the eccentrics into the proper position as near as can be judged, with the rods crossed. Now rotate the eccentric which is in line with the valve stem clear around the shaft and see if the valve uncovers one port as much as it does the other; if it does not do so, change the length of the eccentric rod until it does. Leave the eccentric in its correct position, that is, just showing a little lead for the valve and set it in place with the set screw. Reverse the engine and rotate the other eccentric around the shaft in the same way as the first, observing the travel of the valve and adjusting the length of the rod until it gives an equal movement to the valve either way by the ports. When the correct length is found for this rod rotate the eccentric to its proper position where the valve just shows the proper lead and set the set screw in the hub of the eccentric. If the second rod has been changed very much it will affect the first one and make it necessary to repeat the operation for the first eccentric. If this is done, and great care has been used in measuring the travel of the valve, the operation will be completed. In order to test the work, however, the engine should be placed on the opposite dead center and the lead observed when the reverse lever is first in one end of the quadrant and then in the other. If the lead is not right at this center correct *one-quarter of the error* by moving the valve on its stem and the other quarter by moving the eccentric. Do this with the reverse lever first in one end of the quadrant and then in the other, after which set the set screws in the hubs of the eccentrics down solid, and put on the steam chest cover, being careful to draw all the nuts down evenly. Then after steam has been admitted to the steam chest go over all the nuts again, as the expansion of the bolts, when heated by the steam, will be sufficient to loosen the nuts.

In many link reverse engines the eccentrics are riveted in place and of course can not be changed in length very much. In case it should be necessary to make a slight adjustment at this point, the rivet holes may be filed out a little on one side.

If a new reversing rod has to be inserted, care must be taken to adjust its length so that when the engine is on dead center and the reverse lever is in the middle notch the block will be exactly in the middle of the link.

The link valve is generally set for equal lead, but when so set it will not have equal cut-off, owing to the angularity of the connecting rod. But when properly designed the difference in cut-off may be made quite small and so not affect the distribution of the steam very much. The lead is different at every different point of cut-off, either increasing or decreasing, depending upon whether the rods are open or crossed. In general, it is better to set the valve for the correct lead when the reverse lever is hooked up in the first notch from the "corner," as this is its position when running, unless the work is either very heavy or very light.

Directions for Setting the Shifting Eccentric Gear.—In gears of this class the eccentric slides across the shaft either in a straight line or else along a circular arc. When hooked up the center of the eccentric approaches the center of the shaft, the effect being to shorten the travel of the valve, and increase the angle of advance so that the cut-off occurs earlier in the stroke. These gears may be hooked up as much as desired.

In order to set the valve, first take up all lost motion in the engine parts just as in setting any other valve gear and place the engine on dead center. Now move the hub which carries the guides on which the eccentrics slide around the shaft until a position is found for it where reversing the engine will not move the valve. When this point is found screw the set screws in the hub down solid and then shift the valve on its stem until it has the right lead. Verify the work by turning the engine over on the other center and observing the lead. If it is not the same, correct by moving the valve on its stem a distance equal to half of the error.

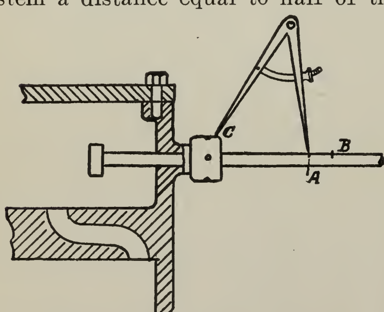


FIGURE 51.

Directions for Setting the Marsh Valve Gear.—The setting of the Marsh valve gear is generally considered a difficult operation, probably because the valve stem is attached to a small crank instead of to an eccentric and because this crank revolves in the opposite direction to the main shaft. As a matter of fact, it is not a difficult operation or one that differs greatly from the setting of a plain slide valve, as will be seen from the following discussion.

The first thing to do is to put the engine on dead center with the crank pin nearest the cylinder.

Second, the set screws located in the bottom and top of the stop ate or casting in front of the crank shaft should each be set out ›out three-quarters of an inch. The exact distance is not impor-nt, as this is only the first trial and is probably not their final ›sition.

Third, move the reverse lever either forward or back, it makes no fference which, until the gear box strikes the screw in the stop plate.

Fourth, make a prick punch mark on the engine frame, steam iest or stuffing box at some convenient place as at *C*, in Figure 51. 'ith one leg of a pair of dividers in this point make a mark with e other on the valve stem, as at *A*.

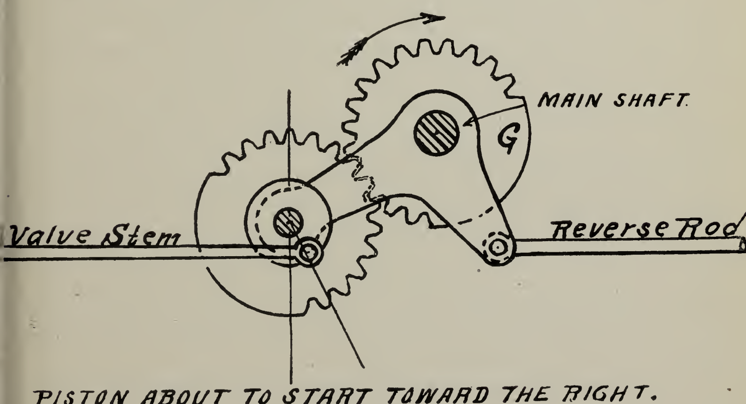


Figure 52.

Fifth, now throw the reverse lever to the opposite end of the quad-ınt and with the dividers still set as before observe if the point *A* omes back to its original position. If, as is often the case, the oint of the dividers falls at *B*, it shows that the main gear *G* on ıe crank shaft, (Figure 52) must be moved a slight amount.

Sixth, after gear *G* has been moved, repeat operation five, and if ecessary make several trials until a position is found for *G* such ıat the point of the dividers will fall at the same place no matter 'hether the reverse lever is forward or back as far as it will go. Vhen this gear is correctly located, fasten it securely to the shaft 'ith the set screw.

Seventh, move the valve on its stem until it shows about one-hirty-second of an inch lead at the head end steam port.

Eighth, place the engine on the other dead center and see if the valve has the same lead.

Ninth, adjust the screws in the nearest stop plate, if the valve has not the same lead as before, until the lead is right, then reverse the engine and, if necessary, adjust the other stop screw until the correct lead is obtained. The valve should now be set correctly, but in order to be sure of results, the engine may be again placed on the head end center and the lead verified.

It is better to set the valve when the engine is steamed up rather than when cold, on account of the expansion of the metal when it is heated, no matter what type of valve gear is being adjusted. With this valve gear, as with all others, be careful to go over all the parts and see that all bolts, set screws and jamb nuts are properly tightened and adjusted before turning on steam, otherwise some part may slip and the whole operation will have to be repeated.

Valves.—There are several styles or types of valves used to admit steam to the cylinders of traction engines which for purposes of study may be classified somewhat as follows: Direct acting valves and indirect valves; balanced valves and unbalanced valves; plain slide valves and piston valves; multiple ported valves and poppet valves. It is not to be understood that the four classes of valves mentioned above are entirely distinct and separate from each other because such is not the case. As a matter of fact, the classes overlap, as will presently be shown; however, by dividing valves in this way, it is much easier to describe them and easier for the reader to get an idea of the different kinds.

A direct acting valve may be defined as a valve that moves in the same direction as the piston at the beginning of the stroke in order to admit steam into the cylinder. An *indirect valve,* on the other hand, moves in the opposite direction to the piston at the beginning of the stroke to admit steam to the cylinder.

While it is true that most traction engine valves are direct acting, there are a few that are indirect. With an indirect valve the eccentric must be set directly opposite to the way it would be set for a direct acting valve, or, in the case of a plain slide valve engine 90 degrees *minus* the angle of advance *behind* the crank instead of 90 degrees *plus* the angle of advance *ahead* of the crank, as is the case with a direct acting valve. Indirect valves are sometimes made in the form of piston valves and sometimes on the plan of plain slide valves. They may be either balanced or not balanced.

Balanced valves are so arranged that the steam in the steam chest can not press upon the back of the valve. In order to accomplish this result the steam must be shut off from the back of the valve by

ne sort of casing or by a plate or ring that fits closely between the lve and the steam chest cover. This plate or ring, however, must st on springs, so that in case water collects in the cylinder the lve will, under the heavy pressure, lift slightly from its seat and ord relief. If the valve is not balanced it is held to its seat with e full pressure of the steam in the steam chest acting upon the iole area of the valve. For example, suppose the valve is six inches de and eight inches long and the steam in the steam chest is der a pressure of one hundred pounds per square inch. Since e area of the valve is forty-eight square inches, the total presre holding it to its seat is 48×100 or 4,800 pounds. With a presre as heavy as this, the valve will consequently be hard to move matter how well it is lubricated, and whatever work is needed move the valve back and forth on its seat is just so much work st in friction. Under these conditions the valve is much more apt become cut or scored because such heavy pressure squeezes the out and, moreover, the eccentric is more apt to heat on account having to pull such a heavy load. Altogether it is much better have the valve balanced. While the actual gain in power in the se of a well built engine can not be very greatly increased, the ease working and the work done by the eccentric and its consequent idency to heat will be greatly reduced.

A plain D slide valve is the commonest type of steam valve used d has been previously described in this book. It is direct acting d may be either balanced or not balanced. A *piston valve* is just e a plain D valve rolled up into the form of a cylinder. Piston lves are always balanced valves, inasmuch as the steam pressure ts equally upon the valve in l directions. When steam is lmitted to the cylinder past the ıds of the valve it is direct actg, but when live steam flows to the cylinder from the middle rtion it becomes an indirect lve. Piston valves, when in good condition, are very excellent lves, but when old and worn they leak steam badly and become isteful.

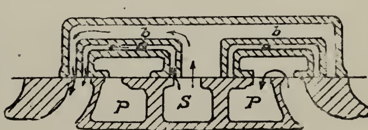


FIGURE 53.

Multiple ported valves are those valves which admit steam to the linder through two or more steam passages. Figure 53 illustrates cross section of a valve of this type known as the Giddings valve. eam reaches the inside of the valve through the main port *S*, ıd from this point travels through ports *a* and *b* in the inrior of the valve to the left hand steam port. The exhaust passes

into the cavity *P,* as indicated by the arrow on the right, and is conducted away by the exhaust pipe—not shown in the figure. The advantage gained by using a valve of this kind is that a small movement of the valve provides a large port opening. In the case of the Giddings valve one-sixteenth of an inch of movement opens the port one-eighth of an inch. This is an advantage because it amounts to the same thing as a quick acting valve which opens the port quickly and closes promptly.

Poppet valves lift straight up from their seats and depend upon some sort of a cam arrangement to lift them and a heavy spring to seat them. They have been used to a very limited extent on traction engines, but find their widest application in very slow moving steam pumps and in gasoline engines.

CHAPTER VIII.

GOVERNORS

Regulation of the Speed of the Engine.—The governor and the fly wheel together regulate the speed of an engine. Variations in speed which extend over a considerable number of revolutions due either to a change in the load or to the steam pressure are taken care of by the governor. Variations that occur during the period of one or two revolutions of the engine are taken care of by the fly wheel.

The object of the governor is to keep the speed of the engine as nearly constant as possible independent of variations in the steam pressure or of the load. No governor so far made can keep the speed exactly uniform because they are themselves driven by the engine and the engine must change its speed first before the governor can act. In the best stationary engines the variation in the speed of the engine does not exceed two per cent. In traction engines the variation is somewhat greater, although even they are governed very closely, for a good governor acts almost instantly and prevents anything beyond a small variation in the speed.

All governors regulate the speed of the engine by proportioning the total pressure which drives the piston throughout the stroke to the work it has to do. This is accomplished in one of two ways:

1. By throttling; that is, changing the pressure of the steam before it reaches the cylinder, the cut-off remaining at a constant fixed point.

2. By varying the point of cut-off in the cylinder, the pressure remaining constant up to the point of cut-off.

These two principles of governing give rise to two distinct types of governors known as *throttling governors and variable expansion governors.*

The throttling governor is placed on the main steam pipe near the steam chest and regulates the steam pressure in the steam chest by making the opening through which the steam must pass either large or small, depending upon the load the engine is pulling. If the load is heavy the opening is large and steam flows into the steam chest at practically boiler pressure, but if the load is light the opening is reduced until only a small quantity of steam can pass into the steam chest and consequently what does get in expands to fill the space and its pressure falls. In the case of a very light load this pressure may be only a small fraction of the boiler pressure. In this

way the governor regulates the total average force acting upon the piston without affecting the point of cut-off. All traction engines so far made are equipped with throttle governors.

The variable expansion governor acts either upon the eccentric or upon the valve and causes cut-off to occur earlier or later, depending upon whether the load is light or heavy. It does not affect the pressure of the steam admitted to the cylinder. The initial steam pressure is therefore constant and practically the same as boiler pressure.

After cut-off the pressure of the steam falls rapidly and consequently the average pressure throughout the stroke may be regulated by the point of cut-off, being low if cut-off is early and high if it is late.

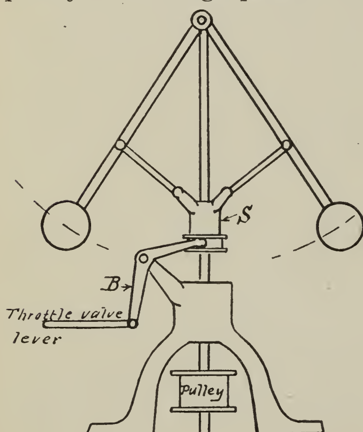


FIGURE 54.

Variable expansion governors are said to be somewhat more economical in the use of steam than throttle governors, but they are not easily adapted to reversible engines and so up to the present time have been used only on fairly large sized stationary engines.

The principle of action of almost all governors of either type depends upon the change in centrifugal force when the speed of rotation changes. If any body be made to rotate rapidly about a center every part of that body has a tendency to get further away from the axis. The force which causes this tendency is called centrifugal force and is due to the rotation of the body. The faster the rotation the greater the force. For example, with the same weight of rotating body, doubling the speed increases the centrifugal force fourfold.

In order to get a clear idea of the action of a governor, we will first consider the oldest and simplest form of throttle governor made, namely, the pendulum governor, an illustration of which appears in Figure 54. The construction of this governor is very simple and can readily be understood from the figure. The pulley at the bottom, driven by a belt from the engine, causes the spindle and balls to rotate, whereupon the balls move upward and outward, elevating the sliding sleeve S and operating the bell crank lever B, which in turn

regulates the opening and closing of the valve through which steam passes to the engine.

With a governor of this type, having certain given dimensions and a certain weight for the balls, it follows that a certain speed of rotation must be attained before the centrifugal force is sufficient to overcome the weight of the balls and cause the governor to act. When this speed is reached the governor begins to act as a governor. If, when the speed increases, the sleeve S reaches the highest point and in doing so does not close the valve which suppplies steam to the engine, then the speed may go on increasing indefinitely, but the governor is no longer acting as a governor. It performs the functions of a governor only within the range of speed which belongs to it while moving from its bottom to its top position. A simple pendulum governor, like the one illustrated, will work fairly well at slow speeds, but when run at a high speed the movement of the sleeve S is very little for a wide variation in speed and so the movement of the throttle valve is insufficient to control the steam supply.

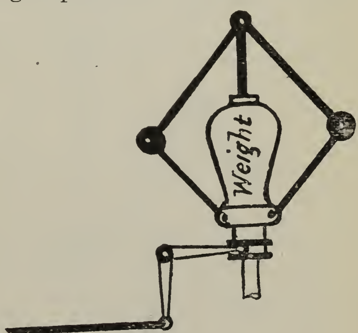


FIGURE 55.

Figure 55 shows a better form of governor and one adapted to fairly high speeds. The balls are light and the spindle is supplied with a weight. This weight resists the centrifugal action of the balls and tends to bring them back quickly to their original position. The vertical distance traveled by the weight and sleeve is just twice that traveled by the balls. The balls are made light and revolve at a high rate of speed in order to develop enough centrifugal force to lift the weight. Since the range of movement of the sleeve is considerable, being twice that of the balls, it makes this governor effective at higher speeds than the pendulum governor.

A governor is said to be *stable* when the balls always assume a given position with a certain speed of rotation, and *unstable* when they assume any position indifferently throughout their range for a given speed of rotation. The condition for stability is that the centrifugal force must increase more rapidly than the radius or distance of the balls from the axis. This will be referred to again in discussing other forms of throttle governors. Modern governors, instead of having a dead weight for a load, are provided with some

sort of a spring load which performs the same office in a better and more satisfactory way. Before taking up this phase of the subject, however, we will proceed to discuss the governing effect of the fly wheel.

The turning force at the crank is not constant. At the beginning of the stroke when the engine is on center it is nothing. From this point until the crank and connecting rod make a right angle with each other it increases, and then decreases again to zero at the other dead center. When the engine is pulling a constant load the force exerted at the rim of the band wheel is always the same. We have therefore an intermittent force acting upon a constant load, and the requirements are that the speed of rotation must be practically uniform some device that will store up energy when the crank re-provide some device that will store up energy when the crank receives its greatest push and give it up again when the crank is passing center. This is the function of the fly wheel. The heavy rim of the fly wheel situated at a considerable distance from the center of the shaft effectually resists the sudden push of the crank for an instant, but in doing so it absorbs the energy of this push and gives it back to the engine when the crank passes center. If the size and weight of the rim is nicely calculated there will be scarcely any change in speed during a rotation of the wheel. On the other hand, without either a fly wheel or a crank disc, an engine would not be able to make a complete revolution, but would stop on the first center. Gas engine fly wheels are made very heavy at the rim in order to absorb enough energy to carry them several revolutions at a uniform speed when they receive no explosion. A fly wheel does not add any to the power of an engine whether it be large or small, it simply tends towards more uniform motion.

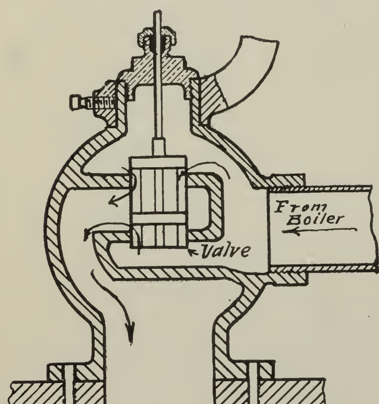


FIGURE 56.

Modern Governors.—The variable expansion governor used largely on stationary engines is generally, though not always, placed on the main shaft and acts directly on the eccentric. One style shifts the eccentric straight across the shaft just like the shifting eccentric reverse gear, explained on a previous page, only it does not shift the

:centric far enough to reverse the engine. The other style of shaft overnor rotates the eccentric around the shaft. Both styles of overnors act just the same as hooking up the reverse lever, thus hanging the point of cut-off. It can readily be seen that a governor of this kind would be hard to adapt to a traction engine hich is already equipped with some device to reverse the engine, ome of which change the position of the eccentric. This leaves he throttle governor as the only available governor so far for the raction engine.

The style in universal use is what is known as the spring loaded ype. The balls are made light and the governor is run at a high rate f speed, usually from about 400 to 450 revolutions per minute. When he balls fly out under the action of centrifugal force, they are obliged to overcome the action of a strong spring which tends to hold them in a position of rest. These springs are so constructed that it takes more centrifugal force to overcome their resistance the farther the balls move outwards. In other words the resistance of the springs increases faster than the centrifugal force does; thus making them *stable* governors; that is, governors which always assume the same position for a given rate of speed.

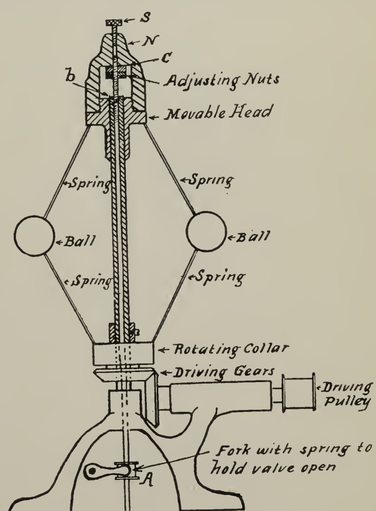


FIGURE 57.

The result of this arrangement is to prevent any sudden variation of the pressure of the steam in the cylinder and to maintain the speed of the engine practically constant.

Figure 56 is a sectional view of the body of a well-known throttle governor. The body is made of iron and the valve and valve seat of brass. Steam flows into the bottom part of the body both from the upper and the lower sides of the valve. In this way the valve is balanced, that is, it receives as much pressure on the top as on the bottom and all the centrifugal force of the balls has to overcome is the weight of the valve and the tension of the springs which hold them back.

The method of regulating the speed of the engine by means of a

governor is accomplished in a variety of ways depending upon the style of the governor. Diagrams illustrating these speed regulating devices are shown in Figures 57 and 58. In Figure 57 the valve is held open when the governor is at rest by means of the fork acting on the collar at *A*. This fork is actuated by means of a long spiral spring whose tension can be made greater or less by means of a thumb nut on the end, thus putting either a light or a heavy load on the valve to hold it up and open. The lower head is stationary while the upper one is free to move downward. The distance the valve is raised from its seat by the fork *A* is regulated by the adjusting nuts. If they are screwed away down on the valve stem the valve will be lifted high and it will require a wide movement of the balls, and consequently a high speed, to bring the surface *C*, of the nut *N*, low enough to close the valve. It will also be perfectly clear that if the adjusting nuts were screwed up near the top of the valve stem that the valve would be forced lower and the port opening would be less, consequently when the balls move out the supply of steam will immediately be throttled and the speed of the engine reduced. When the nuts are screwed clear down, the port opening may be so wide that considerable movement of the valve will be necessary before the steam supply is throttled and the speed of the engine reduced.

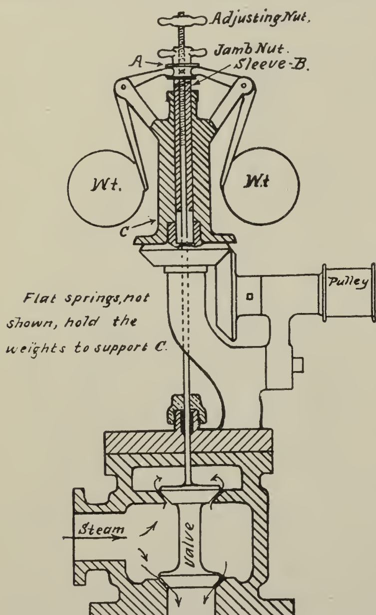


FIGURE 58.

It will also be clear on a little consideration that the adjusting nuts could be screwed clear down or left out entirely and the adjustment made by means of a thumb nut *S* which could be raised or lowered so as to strike the end of the valve stem when the engine attained any desired speed.

Another scheme of regulating the speed is sometimes adopted. In this plan the valve stem is either shortened or lengthened by some device situated between the fork *A* and the nut *N*. The effect of this

device is to either raise the valve from its seat or lower it, depending upon whether the valve stem is shortened or lengthened.

All of these schemes are made use of in the governors applied to traction engines and they are very effective when it is desired to run the engine at a considerably different speed. They must, of course, be used in connection with the speeder spring connected with the fork *A* that puts a load on the valve. This load must be adjusted to correspond to the change in speed, for if the speeder spring were under too great tension the centrifugal force developed by the balls at a reduced speed might not be sufficient to overcome its resistance. The speeder spring itself, as the name implies, can be used to change the speed of the engine within certain limits by making a greater speed of the balls necessary in order to develop enough centrifugal force to overcome its tension.

Another scheme for regulating the speed is shown in Figure 58. In this type of governor the valve stem is threaded through the sleeve *B*, and is provided with a thumb nut at the top with which it may be raised or lowered. A jamb nut below locks the valve stem to the sleeve. A collar at *A*, fastened to the sleeve, is actuated by the balls, which, when they move outward under the action of centrifugal force, push both the sleeve and valve stem down and tend to seat the valve.

When the adjusting nut is screwed up, it lifts the valve farther away from its seat and consequently the balls must move out farther in order to seat the valve. This can only come about by rotating them at a higher rate of speed, but since they receive their motion from the engine, the latter must also run faster before the governor will begin to govern. If the adjusting nut is screwed down, the valve is brought nearer to its seat and hence when the balls begin to move the valve immediately begins to cut off the supply of steam and reduce the speed of the engine. If the speed of the engine is reduced much below normal with this type of governor the steam passages are so much restricted that the engine, while it may govern very nicely, will be supplied with steam at such low pressure that it will not have very much power. Under these conditions, it is better to make the change in speed by changing either the pulley on the governor or the one on the engine shaft so that the governor will run at its normal speed.

Governors of this type are not provided with a speeder spring, but heavy curved springs are attached to the balls and to the rotating head *C*, which resist centrifugal force and tend to bring the balls back to a state of rest.

As before stated, the speed of the engine may be changed by changing the sizes of the pulleys in such a way that the governor will still rotate at its normal speed even though the speed of the engine be greatly changed. In many cases, and especially where close governing is required at a low speed and the maximum power of the engine is required, this is the best way.

The rules for finding the diameter of pulleys are as follows:

To Find the Diameter of the Governor Shaft Pulley.—Multiply the diameter in inches, of the engine shaft pulley, by the desired number of revolutions of the engine per minute and divide the product by the speed stamped upon the governor; the quotient will be the diameter of the governor pulley needed.

To Find the Diameter of the Engine Shaft Pulley.—Multiply the number of revolutions stamped on the governor by the diameter of the governor pulley and divide the product by the speed at which the engine is to run; the quotient will be the required diameter of the engine shaft pulley.

Most throttle governors are equipped with what is called a Sawyer's lever, that is, a lever on the side having a forked arm which engages with a collar on the valve stem. Wires are run from the ends of this lever to the engineer's platform, which enable the engineer to open or close the governor valve forcibly regardless of how the governor may be adjusted, and thus control the speed of the engine by hand.

A large number of governors are also provided with what is called a safety stop. This is so arranged that if the governor belt breaks, the stop causes the governor valve to fall and shut off steam from the engine. In one make of governor a heavy pulley attached to an arm rests on top of the governor belt. When the belt breaks this arm falls and in doing so engages the valve stem and forces the valve to its seat. Another arrangement disengages the bevel driving gears and allows the whole head of the governor to fall and shut off the steam.

CHAPTER IX.

LUBRICANTS AND LUBRICATORS

FRICTION AND LUBRICATION.

Since the earliest times a great many engineers have been seeking earnestly to discover some means for eliminating or at least reducing the friction in machinery to the lowest possible amount, while other engineers have been bending every energy to find some means to increase it for certain purposes. Thus it must be evident that friction has both good qualities and bad ones. It is true that friction has been called the highwayman of mechanical energy and many other names equally as reprehensible, and yet we could scarcely get along without it. But for friction, belt transmission of power would be impossible, trains could not run and men could not walk. For note what happens when the engine drivers strike a greased rail or a man tries to walk on glare ice. Then consider friction brakes and friction clutches and the many mechanical devices that depend upon friction. The engineers who deal in such goods study to increase friction, while those who build machinery aim to eliminate it from every joint and bearing surface.

Both those who aim to eliminate, and those who seek to increase friction, have been fairly successful in their efforts. The first by nice workmanship, by using the proper metals at the right points, and by greater care and skill in preparing lubricants that are adapted to the work; the latter also, strange as it may seem, by more accurate workmanship and by the careful selection and preparation of materials. As an illustration of the latter, it may be mentioned that a perfectly smooth, true clutch shoe acting on a smooth, though not lubricated, surface will grip better than if both were rough. A soft, pliable belt will grip a smooth pulley better than a hard belt will grip a rough one, and a leather belt will grip a wooden pulley better than it will an iron pulley, and a rubber or canvas belt will do better than leather.

This lesson, however, is not concerned so much with friction and how it may be increased, as it is with lubrication and the elimination of friction.

The general effect of friction in machinery is to cause heating of the adjacent parts, a fact well-known to all practical engineers. The reason is very evident. Wherever there is resistance to any force,

there work must be done, for work is defined as the overcoming of resistance through distance. There is an exact relation between work and heat, and it is well known that a certain amount of work will produce a given quantity of heat; and, conversely, a given quantity of heat is capable of doing a certain amount of work. Whenever work is done on a bearing in overcoming friction, a certain amount of heat will be developed, depending upon the work done. If friction can be eliminated there will be no heating.

The object of lubrication is not only to reduce friction, but to carry away whatever excess of heat may have been generated. It prevents friction by forming a cushion between the bearing surfaces, which keeps the metals apart, and it dissipates the heat by running off from the bearing, as in the case of a pump oiling of bearings, or else vaporizes and carries away heat. Whenever steam forms it absorbs a great quantity of heat, a fact one can realize when he considers that the heat of the fuel fed to a furnace is absorbed and passes away with the steam. Likewise with any other liquid that vaporizes, it carries away a large quantity of heat, and it is so with the oil that vaporizes from a bearing. Of course, the vaporizing of the oil and the carrying away of heat, is not the primary function of a lubricant; it is only incidental, because to vaporize it must be heated, and this condition should not arise.

Good workmanship consisting of nicely fitted parts, smooth and well finished, help to eliminate friction provided the assembling is done accurately and all parts are in perfect alignment. This latter consideration, the proper alignment, is all important for smooth, easy running, yet it is where much trouble arises, especially in threshing machinery. Not that the manufacturer does not do his work well, as a rule, although doubtless there are exceptions, but the man in the field is more often at fault by allowing his machinery to get in bad shape.

The selection of materials is another thing that has helped on toward the goal of perfection. Steel shafting working in brass or babbitt boxes, runs with much less friction than in iron boxes however well made, and here the quality of the brass or babbitt becomes another important factor.

To illustrate the great advancement made in reducing friction in engine building, the following is pertinent. A well-known authority says the internal friction of engines twenty years ago ran as high as fifteen or twenty per cent. On some recent tests of traction engines at the plant of one of the great thresher houses, the internal friction ran as low as three per cent and as high as eight under ad-

verse conditions. Good stationary engines of large size run now-a-days with as low as two per cent friction.

Now that we have discussed friction and lubrication in a general way, we will proceed to look into the matter of lubricants.

Lubricants are derived from three principal sources, namely, animal, vegetable and mineral. Mineral lubricants are of fairly recent origin, having come into general use within the last thirty years. It may be interesting to know in this connection that the development of very high pressure of steam engines and of the gas engine was only made possible since petroleum oils and their compounds were discovered, but more of this later on.

The animal oils include the oils of animals and fishes. The most important are lard oil, tallow and neat's-foot oil. The various fish oils such as whale oil, sperm oil, black fish oil and porpoise oil while valuable are of secondary importance.

Lard is the best all around animal lubricant and is well adapted to medium and light machinery. It is the best oil known for use on dies for cutting bolt threads or pipe threads and is also used on lathe tools where a very fine, smooth cut is desired.

Before petroleum oils were developed tallow was used as the principal steam cylinder oil. It worked quite successfully, too, for the pressures then in vogue but it would not be suitable for the high pressures used today because it would decompose with the heat. It contains a certain amount of free acid too that is objectionable in that it attacks the metal that it comes in contact with. Most oils contain some acid and leading authorities on the subject say that three per cent or more present in an oil should condemn it for lubricating purposes.

Neat's-foot oil is derived from the hoofs and bones of cattle. It is a fairly good lubricant for machinery but its principal use is as a belt dressing for leather belts and for harnesses. Only a little should be applied to the leather, just what can be absorbed. It acts as a softener and as a preservative. If separator belts were cleaned and given a dressing with neat's-foot oil at the close of each season's run before being put away they would last a good deal longer.

Black fish oil has been used quite largely for guns and sewing machines but in recent years it has been largely displaced by the cheaper paraffine oils derived from petroleum.

Sperm oil is very expensive and is used very little except possibly for watches and similar delicate mechanism.

Vegetable oils are expressed from the seeds and fruits of plants. Those most largely manufactured are cotton seed oil, olive oil, linseed oil and rape seed oil.

Olive oil is probably the best of the vegetable oils for machinery but it is too expensive for general use.

Linseed oil which is made from flax seed is absolutely worthless as a lubricant because it very quickly becomes hard and gummy. This property which unfits it for use as a lubricant, however, is the very thing which gives it especial value in mixing paints. It dries readily and in doing so forms a thin rubber-like coat over the painted surface.

Rape seed oil is made on the continent of Europe and is said to be used in preparing the better grades of hard oils.

The mineral oils are all made from petroleum or from rock rich in petroleum products. After the lighter oils have been distilled off the residue is raised to a higher temperature and the different grades of lubricating oils are obtained. These oils vary from the light paraffine oils to the heavier grades of engine oils.

In addition to the oils above mentioned we have the following dry or solid lubricants, namely, graphite, mica, sulphur and soapstone. Of these four, graphite is the most widely known and is the best. It is excellent to use on a roughened bearing when mixed with grease. It is also excellent for a hot bearing when used in the same way. Mica is also sometimes used mixed with grease, but it is not as good as graphite. While these solid lubricants are good to smooth the inequalities in a bearing and for use on packing, they do not take the place of oil or grease. In all cases they should be used sparingly.

In addition to the lubricants noted above there is another large class which comes under the head of greases or hard oils. These have as a base either animal, vegetable or mineral oils. The best grade of hard oil is made chemically by boiling either animal or vegetable oils in lime water thus making a sort of insoluble soap. Soap is made in the same way by using caustic potash instead of lime. Mineral hard oil has a paraffine base and is not quite as good a lubricant as the hard oils made from animal or vegetable oils. However, it is much cheaper and for many classes of work it is quite satisfactory notwithstanding the fact that it requires a larger quantity than the former for the same class of bearings. In general it may be said that greases are not as good lubricants as liquid oils, a fact which has been proven by many careful scientific tests. Its ease of application, however, and its cleanliness more than compensate for the slight difference in lubricating qualities, especially for such places as the crank pin, cross head pin and other moving parts of machinery. The various axle greases also come under the head of hard oils and are valuable for the purpose for which they are intended.

The value of a lubricant is said to be largely dependent upon the number of greasy particles it contains and upon its viscosity. A viscous oil is one that is syrupy in consistency. Thick, heavy oils are generally the most viscous but this is not always true because sometimes oils are adulterated to improve their viscosity. An oil treated in this way is of course a very inferior lubricant. An analysis of some of these oils show that they contain a considerable amount of gelatine, a substance having absolutely no lubricating value.

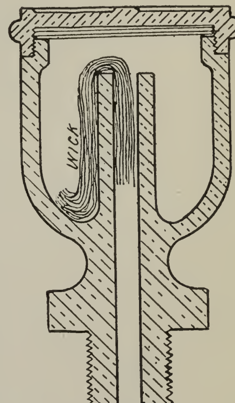


FIGURE 59.

A good oil should, as previously stated, contain not to exceed three per cent of free acid, in fact, a perfectly neutral oil, one containing no acid at all, is the best. An oil should not dry out and become gummy. It should not contain any grit or dirt or any other foreign substance, neither should it become rancid nor bad smelling when exposed to the air for a considerable length of time. In addition to all this, the oil should be adapted to the work in hand. A heavy oil for a large heavy bearing and a light thin oil for light machinery, is the general rule. Guns, cream separators and sewing machines require a light oil which would be totally unsuited for the bearings around a grain separator or the main bearings of an engine.

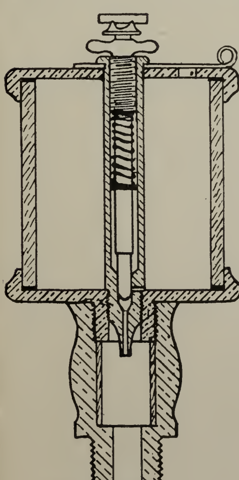


FIGURE 60.

Cylinder oils are in a class by themselves. Here we must have an oil that has considerable body and which will stand a high degree of temperature without decomposing or breaking up. In other words it must have a high flash point. The flash point of an oil is the temperature at which a vapor is given off that will take fire.

The usual method of making a flash test is to put some of the oil in an iron cup, then place this in a tin dish with dry sand in the bottom and place over a fire. A thermometer that will read to 500 or 600 degrees Fahrenheit should be placed in the oil and after the temperature reaches say 300 degrees, pass a lighted match over the top of

the cup every time the temperature goes up ten or fifteen degrees. When the vapor takes fire the thermometer shows the flash point of the oil.

Steam at one hundred pounds gauge pressure has a temperature of 337 degrees and at one hundred fifty pounds the temperature is 361 degrees. Consequently the oil used for cylinder lubricating purposes should have a flash point considerably higher than these temperatures. For ordinary steam engine practice a flash point of 400 degrees is considered about right. For gas engine practice where the cylinder temperatures are very much higher, a still higher flash point is desirable.

An oil suitable for steam engine cylinders is generally unsuited to gas engines. Steam cylinder oil is what is known as a compounded oil and is made by mixing either an animal or a vegetable oil with a mineral oil. The compound thus partakes of the nature of both. A pure mineral oil will not form an emulsion with water and hence will not adhere to a moist surface. For this reason it is useless for steam cylinders. It has, however, a high flash point which the animal oils do not possess. The compound of the two forms an oil that possesses the characteristics of both and makes a very much better lubricant than either alone.

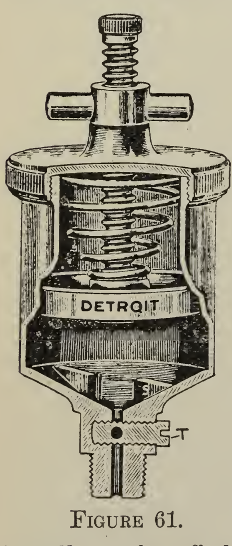


FIGURE 61.

A cylinder oil when adapted to the pressure carried will atomize or break up into a very fine spray (not a vapor) when caught in the current of steam and becomes intimately mixed with it, thus finding its way to every part that the steam reaches and producing perfect lubrication. If oil of too low a flash point is used it will be decomposed by the steam forming a gas and its power of lubrication is completely lost. On the other hand, a very heavy oil of too high flash test may not be even atomized, in which case it simply flows down along the inside of the steam pipe and forms a pool in the steam chest. Here again lubrication is a failure. In case a rather heavy oil is used and difficulty is experienced in getting good lubrication it is well to take off the steam chest cover and observe if there is oil in the bottom of the chest. If there is, it is evidence that the oil is too heavy and a change should be made to one somewhat lighter.

Less trouble will generally be experienced with cylinder lubrication if care is taken to see that the small delivery pipe of the lubricator projects well into the steam pipe where the drop of oil will be caught in the current of steam. If the drop simply discharges along the side of the pipe it is much more apt to run down without becoming atomized.

Lack of lubrication in a steam engine cylinder can be recognized by a groaning noise in the cylinder and by the jerking of the valve. If not well lubricated, the valve and valve seat are pretty sure to become scored and likewise the cylinder and piston rings. No general rule can be given as to just the amount of oil to use. This depends upon the workmanship throughout on the engine, whether there is much water in the steam, and whether the engine is new or has been run for some time. If the cylinder is bored smoothly and the workmanship is first class, less oil will be required than where the work is done in an indifferent manner.

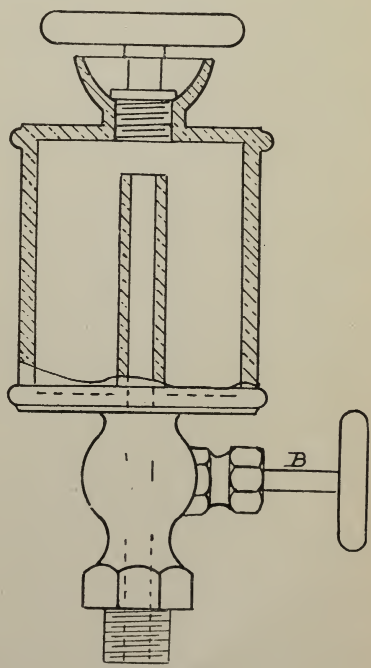


FIGURE 62.

An engine that primes requires a large amount of oil because the water in the steam washes the oil out. In a case of this kind the difficulty may be due to bad water or it may be due to lack of steam space in the boiler. If bad water is the cause the boiler will foam, but if the trouble lies in the proportioning of the boiler, priming may be looked for instead of foaming. Whenever an engine primes badly the cylinder needs a large amount of oil at once and for this purpose a small hand oil pump is desirable. Some traction engines are regularly equipped in this way. Where the water is strongly alkaline it is always well to have an oil pump as a part of the regular equipment. A new engine always requires more oil than one that has been run a considerable time because no matter how carefully the work may have been done the cylinder, the piston and valve

are considerably rougher than they will be after having run some time, provided of course, the engine has been well cared for. In the same way, and for the same reason, the other bearings of a new engine require more oil than one that has been run for some time and there is much more danger of heating.

Some engines require only four or five drops of oil per minute and some require twenty or thirty, depending upon the conditions above described, consequently no general rule can be laid down covering cylinder lubrication.

For lubricating gas engine cylinders a pure mineral oil is used. Here the metal is dry and the heat is intense. At the moment of explosion the temperature ranges between 2,000 and 3,000 degrees. The cylinder walls are generally jacketed either with water or oil which keeps the temperature of the metal from becoming dangerous. Nevertheless, the heat is considerable and it requires an oil of from 400 to 600 degrees flash point. A mineral oil has the property of spreading over a dry surface and it can be procured with any flash point desired. For water cooled engines where the jacket water does not get very hot, a pure mineral oil from 400 to 450 degrees flash point will give good satisfaction and will generally give even better satisfaction than the more expensive kinds showing a higher test. With oil cooled or air cooled gas engines which run hotter, a higher test oil should be used.

Oil that burns on the gas engine piston always causes trouble by forming a carbonaceous substance that causes the piston rings to stick and also gets between the valves and valve seats, causing trouble.

Oil that is used on the main bearings of a traction engine should be able to withstand the heat at that point without evaporating. The temperature of the main bearings is almost the same as that of the boiler to which they are attached and if an oil is used that evaporates quickly, that which remains becomes thick and gummy and useless as a lubricant. A good test for an oil to be used for the main bearings is to drop a little oil on the boiler near them and observe if it burns quickly, if so it is not suitable.

In conclusion, the writer wishes to advise buying the oil from a reputable dealer and when a brand is found that is suitable for the work in hand stick to it. It is very easy to adulterate oils and only an expert in oils can tell much about them, and then only after a careful test and analysis. There are a number of firms which make good lubricants and quite a good many others that make a cheap article that is practically worthless. Since the good working as well as the life of the machinery depends so largely upon lubrication, too great care can not be exercised in the selection of the lubricants.

LUBRICATORS.

There are a great many different styles and forms of lubricators used on machinery. At first sight one might think it would be impossible to make a systematic classification. A little thought, however, will make it evident that there are two primary classes, namely, bearing lubricators and steam lubricators. The former are used on the bearings of all classes of machinery, the latter for the cylinders and valves of steam engines. The different lubricators used on bearings naturally fall into the following classes: plain lubricators, sight-feed oilers, grease cups (both plain and automatic) and pumps.

Figure 59 shows one of the simplest forms of plain lubricators, or wick oiler, as it is generally called. It is a plain brass cup having a central tube extending well up toward the cover. A few strands of candle wicking are pushed down into the tube, leaving a coil on the outside in the oil. The oil rises in the wick by capillary attraction just as it does in a lamp wick, and flows down the tube to the bearing. The only method of regulation is to add more strands of wicking to increase the flow or take out some to reduce it. Close regulation is, of course, out of the question. This form of lubricator is not used on traction engines at the present time.

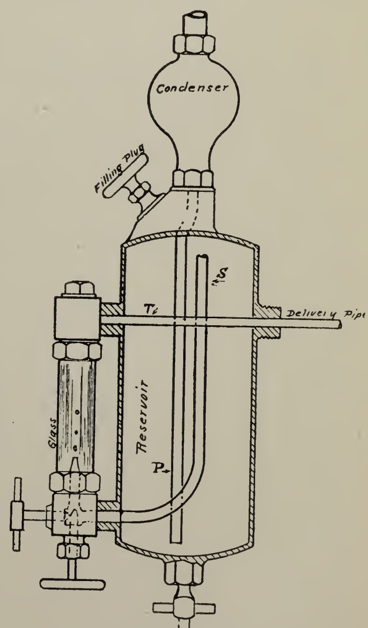


FIGURE 63.

A sectional view of an ordinary sight feed oiler is made the subject of illustration in Figure 60. The oil is contained in a glass reservoir which has ground ends and is made oil tight by means of gaskets at the top and bottom. The cover is screwed down on a central tube extending up through the reservoir. The bottom of this tube is provided with a valve seat for a needle valve. This needle valve extends up through the tube and is provided with a cross bar or eccentric lever wherewith it may be raised from its seat. It is held down normally by a small spiral spring in the upper part of the tube. A thumb nut at the top may be raised or lowered, thus in-

creasing or decreasing the distance the needle valve moves from its seat and so regulating the flow of oil. A sight feed glass below the reservoir shows how much oil is being delivered. If oil rises in this glass it shows that the opening below is obstructed and needs cleaning out.

Figure 61 shows an automatic grease cup. It is provided with a plunger resting upon the grease which is pressed down by means of a strong spiral spring between the plunger and the cover. The plunger spindle is threaded and extends up through the cover. A thumb nut at this point enables the operator to compress the spring and lift the plunger off from the grease. When working, the thumb nut is unscrewed until it is free from the cover. When the machine is stopped the nut should be screwed down until the plunger is lifted off from the grease. A screw in the spindle of the oiler below the reservois is provided with an opening the same size as that in the spindle. This opening is parallel with the slot in the head of the screw. By turning this screw so that the opening in the spindle is reduced, it is easy to govern the flow of oil to the bearing.

Cylinder lubrication may be divided into the following classes, namely, water displacement lubricators, hydrostatic lubricators, and mechanical lubricators or pumps.

The first one of these to be described is the water displacement lubricator, which is shown in Figure 62. It consists of a brass reservoir having a central tube open at the top, which reaches up almost to the cover. Below the reservoir a valve B is provided which shuts the opening between the steam space and the reservoir. A sight feed glass may be inserted below the reservoir and generally is, although some oilers of this sort, like the one illustrated, are made blind.

The principle of operation is as follows: When the valve B is opened, steam from the steam chest rises through the central tube, condenses by meeting the cold tube and cover and the water being heavier than the oil flows down the outside of the tube to the bottom of the reservoir. If the reservoir is full, an equal amount of oil will be displaced and, having no other place of egress, will flow down the tube to the steam chest. This operation continues until the reservoir is filled with water and emptied of oil. Without the central tube a lubricator of this kind would be unable to work as long as steam presssure was on.

The hydrostatic lubricator, one form of which is illustrated in Figure 63, depends for its operation upon the weight of a column of water acting upon the oil and forcing it out into the steam main. The lubricator shown has two connections to the steam main, one

at the top, the other at the side. To put the lubricator in operation, first fill the reservoir completely full of oil. Then open the valve in the delivery pipe (not shown in the figure) and the one on the back side of the upper part of the gauge glass (also not shown in the figure) and allow the sight feed glass to fill with water. Now open the valve in the upper connection and regulate the feed of oil with the valve below the sight feed glass. The action is as follows: Steam flows down the pipe above the reservoir and condenses both in the steam pipe and in the globular brass condenser bulb just above the reservoir. The water resulting from condensation flows up the pipe P to the bottom of the reservoir and displaces an equal amount of oil which enters the pipe S, at the top of the reservoir and flows down and then up into the sight feed glass. Here the drop is liberated and rises through the water and thence flows across through pipe T to the steam main where it is caught in the current of steam and whirled along toward the cylinder. When the lubricator is working, the upper pipe is filled with water. The steam pressure at the lower connection is the same as at the upper. Thus the pressures due to the steam are balanced, but the weight of the column of water in the condenser pipe acting upon the oil pushes it out into the steam main. The longer the condenser pipe is the greater will be the pressure on the oil.

In single connection lubricators there is a loop above for a condenser pipe and the height of the column of water which moves the oil is measured from the top of the loop to the bottom of the reservoir.

Care should be taken in connecting up hydrostatic lubricators that all joints be tight. A leak anywhere may offset the weight of the column of water and make it fail to work. The cause of the glass getting dirty is often due to running the oil entirely out of the reservoir, then if the steam pressure is very high the last of the oil may become heated to such an extent that the drops burst when they come up into the sight feed glass. The fouling of the glass may happen if the delivery jet in the glass becomes roughened or bruised, causing the drop to strike the glass instead of rising straight through the water.

CHAPTER X.

GEARING, BELTING, CARE OF ENGINE

THE DIFFERENTIAL GEAR.

Every road engine, be it traction engine or automobile, must be provided with some sort of device to enable one of the drive wheels to turn faster than the other in turning a corner. If this were not done, the inner wheel in turning a corner would have to slip because the outer wheel has so much farther to go, being on the outside of the circle. This slipping, in the case of an automobile, would wear the tires badly and in the case of a traction engine it would throw very heavy strains on the gearing and rest of the machinery, owing to the weight of the engine and the grouters with which the road wheels are provided to keep them from slipping.

The mechanism which allows one of the drive wheels to move faster than the other is called the differential gear and sometimes the compensating gear, either term being used to mean the same thing.

In order to describe the construction and operation of a differential gear, constant reference must be made to the accompanying illustration, Figure 64, which shows the main shaft and counter shaft together with all the gears of the driving mechanism in their proper relative positions. The figure is not drawn to scale and is intended merely to illustrate the arrangement of the mechanism, rather than the proportions.

Power is transmitted from the main shaft to the drive wheels through the train of spur gears shown in the drawing. These consist of a driving pinion, A, intermediate gear, B, differential gear, C, master pinion, D, and a master gear. The driving pinion does not revolve with the main shaft excepting when the engine is moving on the road.

When necessary to put the traction wheels in motion it may be locked to the main shaft by means of the friction clutch. The intermediate gear, if there is one, is attached to a stub axle bolted to the side of the boiler. All this gear does is to bridge the gap between the driving pinion and the differential gear.

This latter gear is attached to the counter shaft and instead of being a single gear as the others above mentioned, it is an aggregation of gears, consisting of first an outer ring or drum with teeth on the outside which mesh with the intermediate gear. Between

the hub and the outer rim there are a number of bevel pinions, marked F, in the drawing, which are attached to and revolve with the outer shell C. These pinions are also free to revolve on their own axes.

Two bevel gears, H and K, one on each side of the large gear, C, mesh with the bevel pinions. The inner gear, H, is keyed to the counter shaft, while the outer one, K, runs loose. The hub of gear K is made long and is provided with teeth, thus forming the master pinion D. The companion driving pinion, M, on the opposite end of the counter shaft is securely keyed in place.

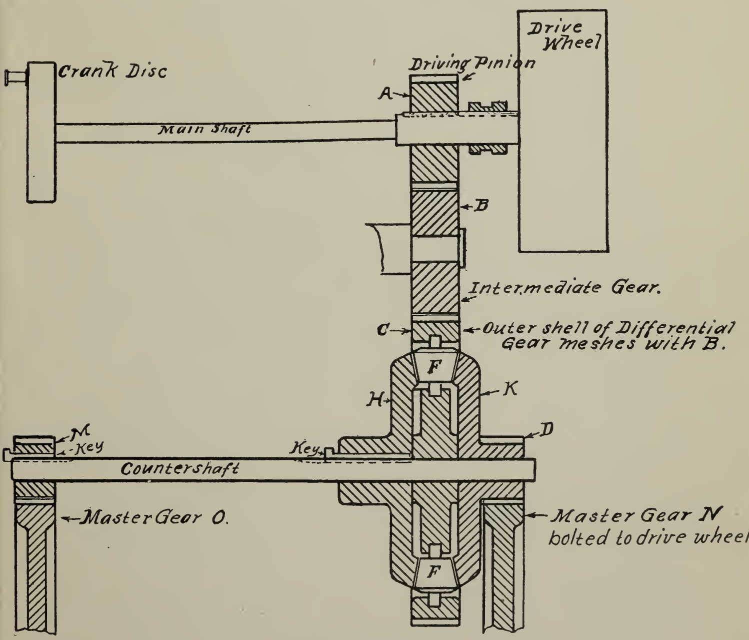


FIGURE 64.

When both road wheels, N and O, meet with the same resistance, as in travelling along a straight road, the whole differential gear revolves as one gear, transmitting equal driving power to both road wheels. If gear M, however, were lifted off the ground it would meet with no resistance, while O, being still on the ground, would meet with considerable resistance. Under these conditions the pin-

ions F would revolve and cause bevel gear K and spur wheel D to revolve, thus causing the master gear N and its road wheel to revolve, while the counter shaft and the road wheel O remain at rest.

On the other hand if O were raised from the ground and N met with resistance, the pinions F would again be set in motion causing gear H to revolve and with it the counter shaft and road wheel O, but since bevel gear K is loose on the shaft it will not turn and so the wheel N will stand still.

In going round a curve the inner wheel does not have to travel as far as the outer one and so meets with greater resistance. Consequently the bevel pinions in the differential gear revolve a sufficient amount to enable both wheels to travel the required amount without either slipping.

If one wheel gets in the mud where it does not meet sufficient resistance, the one on hard ground will stand still, while the one in the mud will revolve rapidly and dig deeper without moving the engine. In order to overcome this difficulty some provision is made either to lock the differential so that it must act as a solid gear, either with a pin or rachet, or to lock both drive wheels to the axle, in case the engine has a through axle. Care must be taken to unlock the differential or the rear axle before turning a corner. If this is not done great strain will be thrown on the differential which will almost certainly result in broken pinions. There is no side thrust on the gears as is the case when bevel gears are used, and consequently not so much strain on any part of the differential gear.

The action of this type of differential is exactly similar to that of the one just described and a careful inspection of the drawing should make its construction and operation perfectly plain to the reader.

Automobiles, generally, and some makes of traction engines, are provided with a differential gear having spur pinions instead of bevel pinions. These spur pinions mesh with an annular gear, that is, a gear having teeth cut on the inner surface. The action of a differential gear of this kind is exactly the same as that of the one just described. The claim of superiority made for the differential gear with spur pinions is that there is no side thrust on the gears as there must be where bevel gears are used, and consequently there is not so much strain on any part of the differential gear.

On the other hand, it has the disadvantage of working with a master gear of relatively small size which makes it difficult to proportion the other gears in the driving train to the best advantage in traction engines.

BELTING AND TRANSMISSION OF POWER.

There are three kinds of belts in common use, leather, rubber and canvas. Leather has been used since very early times, but rubber and canvas have come into use within comparatively recent years.

Ropes and chains are used also to transmit power, and within the past few years metallic link belting has come into use for some kinds of work. The threshermen, however, are interested directly only in the three kinds first named.

The best leather belting is made from the backs of the hides of steers. Cow hides do not make first-class belting, although considerable quantities are worked into the inferior grades of belting. Figure 65 illustrates a skin after it has been tanned. The middle portion, *E, F, G, N,* cut from the middle of the back, is used in making what is known as strictly short lap belting, and is used in the highest grade goods. The parts outside of this middle portion are used for belting of inferior quality. The stock cut from the neck is uneven in thickness and stretches unevenly. It is not suitable for belt stock.

Single belting is made from a single thickness of skin. To make a long belt the strips of leather are glued together. Care is taken to make the belt perfectly straight. If it is only slightly crooked it will never run straight on the pulleys.

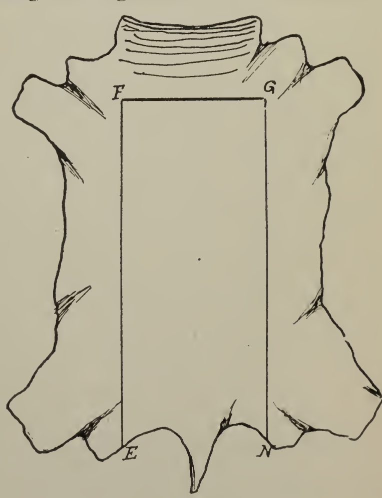


FIGURE 65.

Double belting consists of a double thickness of skin glued together. When made in this way the hair or smooth sides are brought to the outside.

In transmitting power by means of belting, the friction of the belt on the pulleys is the working principle made use of. It has been found by experiment that the softer and more pliable the belt, the better it will grip the pulleys and the more power it will transmit without slipping.

The hair side of the belt should always be run next to the pulley because, being smoother, it presents more surface in contact with the pulley and hence will

transmit more power without slipping than if put on the other way. A belt put on in this way will last longer because the short non-elastic fibers are brought to the inside where they are under compression instead of tension when bending around the pulleys. If they were on the outside away from the pulley and under tension, the belt would be liable to crack. Tests made by running a belt, first with the hair side next to the pulley and then with the flesh side, show that the former method will transmit twenty-five per cent more power.

The tensile strength of leather belting is very variable and ranges from two thousand to five thousand pounds per square inch of cross section. That is, a belt one inch square, or what is the same thing, one-fourth of an inch thick and four inches wide, will break under a load of from two thousand to five thousand pounds.

The lacing, or point at which a belt is joined, is the weakest part unless the belt is an endless belt. That is, one that is glued together. Glued belts can be used only in connection with an idler pulley or belt tightener to take up the stretch.

New leather belts always stretch more or less and it is a good plan when starting a new separator to cut the belts an inch short and then as they stretch take up the slack. It must not be forgotten that a large part of the difficulty experienced with grain separators is due to loose belts. If a belt anywhere on the machine slips, the part that it drives is running at a relatively slower speed than those parts driven by tight belts. Now every part of a separator is speeded at exactly the right rate and if a belt slips anywhere, the result will surely be trouble for the operator. When straw clogs on the racks or the tailings augur becomes choked, the cause can generally be traced to a loose belt which drives these parts too slowly.

As a rule it is not a good plan to use belt dressings, especially those that are sticky or gummy. If a belt is kept at the right tension and is soft and pliable, it is in the best possible condition to do good work. Melted beef tallow put on lightly and then allowed to dry makes a good dressing. Neat's-foot oil on hard dry belts is also good, as is also castor oil. In any event care should be taken not to use very much oil or the belt will stretch and become dead and flabby.

Belts should be kept dry. Rains or heavy dews are bad and cause the leather to become hard and brittle. Care should also be taken not to stretch the belts too tight. This puts a heavy strain on all bearings and upon the pulleys which can result only in heated bearings and a gradual getting out of line of the whole machine. Probably as much damage is caused by an over-tight main drive belt as

from any other thing about a threshing rig. The engine is often backed into the belt until it shows hardly any sag. The amount of strain on the bearings under these circumstances is simply tremendous and is sufficient to squeeze out all oil between the shaft and the box. The result will almost surely be a hot box. In fact, the writer has seen the cylinder box on the belt side of a separator melted out from just this cause.

The horse power a leather belt can transmit depends upon three factors,—the speed at which the belt runs, its thickness, and its width. If the speed of the belt be doubled it is able to transmit twice as much power. Likewise, if its width be doubled it can, at the same speed, transmit double the power. Doubling the thickness, on the other hand, increases the power the belt is able to transmit one and seven-tenths times.

A rule usually given for the horse power a leather belt is able to transmit is as follows: A single leather belt one inch wide, traveling one hundred feet per minute, can transmit one horse power. This assumes that the arc of contact that the belt makes on the smaller pulley is equal to 180 degrees, or half the circumference of the pulley. Working on this basis we have the following table which represents the power which belts of different widths can safely transmit when the velocity is one hundred feet per minute.

Width of belt in inches	Horse power for single belting	Horse power for double belting
1 inch	.09	.153
2 inches	.18	.306
3 inches	.27	.459
4 inches	.36	.612
5 inches	.45	.765
6 inches	.55	.935
7 inches	.64	1.008
8 inches	.73	1.241
9 inches	.82	1.394
10 inches	.91	1.547
11 inches	1.00	1.700
12 inches	1.09	1.760

The following problem will illustrate the use of the table: A double leather belt eight inches wide passes over a thirty-six inch pulley which makes 350 revolutions per minute. What power will the belt transmit safely?

Solution.—The speed of the belt will equal the rim speed of the pulley. Every time the pulley revolves, a point on the rim will

travel a distance equal to its circumference. The circumference of a three-foot pulley is 3×3.1416 which equals 9.4248 feet. 9.4248×350 equals 3,298.88 feet, the speed of the belt. In round numbers the belt speed is 3,300 feet per minute.

From the table we find that an eight-inch belt traveling one hundred feet per minute will transmit 1.241 horse power. Then at 3,300 feet per minute, it will transmit 33×1.241, which equals 40.95 horse power.

Canvas belts, often miscalled Gandy belts, are used very largely for main drive belts. They are much cheaper than either leather or rubber and give very satisfactory service. They are first woven from strong cotton yarn. The webs are woven in lengths of six hundred feet. A separate width is woven for each width of finished belting, that is, a twenty-four inch width for a four-ply, six-inch belt; a thirty-two inch width for a four-ply, eight-inch belt, and so on. This insures two selvedge edges on each piece of duck which enters into a belt.

After the duck is woven, it is folded and then stitched, the rows of stitches being one-fourth of an inch apart, except at the splice, where they are one-eighth of an inch apart. When the web is folded over four times, making four thicknesses, the belting is said to be four-ply, five thicknesses, five-ply, etc.

After the belt is stitched and spliced, making it endless, it is covered with self oxidizing oils until the canvas is saturated. After this it is hung up in dry sheds and allowed to dry, during which time the oil oxidizes. After the drying process is completed it is taken down and given a coating of paint which generally consists of iron oxide and venetian red. After a final drying, it is ready for the market.

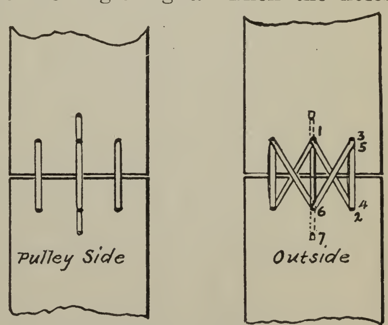
The oils and paint fill the duck and prevent it from taking up moisture. Belts made in this way are more suitable for severe weather conditions than leather belts. The strength of the duck from which canvas belts are made is said to be about three hundred fifty pounds per inch of width for a single thickness, thus making a four-ply canvas belt considerably stronger than a single leather belt.

Rubber belting is first made of a rather loosely woven cotton duck, after which unvulcanized rubber is squeezed in between the meshes of the cloth. The web is then folded and the rubber is vulcanized. Rubber belting when well made is very serviceable for out of door work. It is not quite as strong as canvas stitched belting and will not bear such rough usage.

Belt Fastenings.—There are several different ways to fasten the ends of a leather belt together; as for example, lacing, gluing, and by the use of metallic fasteners. All of these methods are in common use and all of them are satisfactory under certain conditions. Lacing is used more widely than any other method, principally for the reason that it is the most convenient and easiest method that we have.

There are quite a good many ways of lacing a belt to make a satisfactory fastening. There are, evidently, judging from the appearances of many belts in use, a great many people who do not know how to perform the operation correctly. This article is intended to show several simple methods of lacing, both narrow and medium sized belts, in a good workman-like manner. Many people seem to think that the lacing should be thick and heavy in order to make a good job. This, however, is a mistake. The thinner the joint, if it is made correctly, the better it is. A thick, heavy lacing strains the belt in passing over the pulley and causes slippage, for the reason that only a few points are in contact with the pulley at the instant it is passing over.

The first thing to do is to cut the ends of the belt perfectly square, using a square in order to make the angle right. Then the holes should be punched with the right sized punch, that is, with one that will not remove any more leather than is necessary to allow the lacing to pass through without tearing the belt. An oval punch held lengthwise of the belt is the best form of punch to use. The holes should not be nearer than three-quarters of an inch to the sides of the belt, nor nearer than seven-eighths of an inch to the end that has been cut off. The holes in the two ends of the belt should be laid out so that they match each other exactly. Then when the tension is applied to the belt, the two ends will be exactly in line.



For Narrow Belts
FIGURE 66.

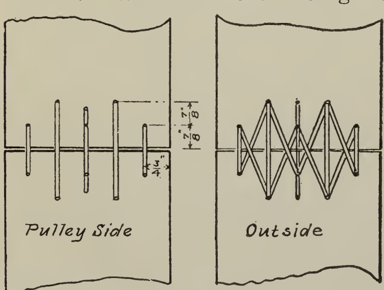
Figure 66 represents a style of lacing adapted to narrow belts that do not have to transmit very much power. The two ends of the lacing should be drawn through from the smooth or hair side of the belt. One of the laces is then laced toward the right side of the belt,

and then back again to the middle, taking care to keep the strands of the lacing parallel with the belt on the pulley side, and to make all the crossings on the outside of the belt. The other end of the lace is carried to the left side of the belt, and back again to the middle in a similar manner. The laces should never cross on the pulley side for the reason that they will wear in two at the point of crossing. This lacing can be easily learned by following the figures shown on the cut, that is, start at 1 in the center, then lace through holes 1, 2, 3, etc., with the right hand lace, and do the same for the left hand.

Figure 67 shows a simple method of lacing a heavier belt. The starting point is in the middle and the direction for the laces is indicated by the drawing.

A hinge lacing suitable for a governor belt or for a blower belt is shown in figure 68. The ends of the laces in every case pass through between the ends of the belt before passing through a hole. The ends of the lacing are fastened, as shown in the cut, near the edges of the belt. This style of lacing permits the belt to pass over a small pulley or to make a short, sharp bend. It is not as strong as the other lacing shown, but it is much more flexible, and for certain purposes, as for example those above mentioned, it has considerable merit.

The next illustration, figure 69, represents a style of lacing suitable for heavy belting which transmits a large amount of power. The starting point for this lacing is in the middle of the belt, one end of the lace being carried to the right, the other to the left. Care should be taken in making this lacing, as indeed with all of the others, to keep all the strands of the leather lacing at an even tension. Whenever the lacing stretches on one side of the belt more than upon the other, either the lacing or the belt is apt to tear, and it will be impossible to keep the belt on the pulley.



For Medium Belts
FIGURE 67.

Belts used for driving high speed machines, especially if they pass over small pulleys, will give better satisfaction if glued together, than if laces are used. The belt being smooth at all points has no tendency to jump or slip in going over the pulleys as does a belt that is

laced. Difficulty may be experienced, however, through the stretching of the belt, unless some provision is made to move the machine that is being driven, on a rail, as is generally done in the case of small electric generators, or by means of a tightener pulley which takes up the slack of the belt.

The method of gluing a belt is well illustrated in Figure 70. The two ends of the belt should be scarfed as shown in the illustration so that when they are laid together the thickness of the joint is exactly the same as the rest of the belt. The length of the lap should be about ten inches on all belts less than ten inches wide. The scarfing can be done with a sharp carpenter's plane. A good grade of fish glue should be spread on the two halves of the belt, and the joint completed by clamping together between two smooth planks. The pressure should be left on about twenty-four hours. A glued belt should not be put in service until forty-eight hours have elapsed from the time of gluing.

Rubber belts and canvas belts are sometimes laced, but the joint is never very strong; in fact, there is no very satisfactory method known to join these belts. If lacing is resorted to, an awl should be used to make holes, instead of a punch. A punch will cut the strands, while the awl merely pushes them to one side and does not weaken the belt at that point. Where the belts do not have to pass over very small pulleys, there are a number of special belt clamps and plates on the market that will join the belt much more satisfactorily than in any other way.

Metallic belt fasteners and wire lacing are used widely on small and medium sized leather belts. These fasteners are made in a variety of forms, sometimes as staples, and sometimes in the form of a hinge with a pin. Where very heavy loads have to be transmitted, there is danger that the staples will cut through the leather. For all ordinary work, however, they are very satisfactory, cheap, and easy to apply.

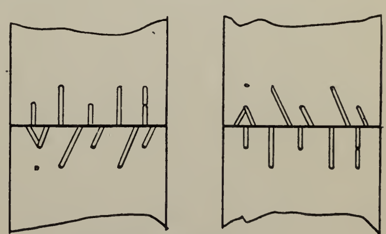
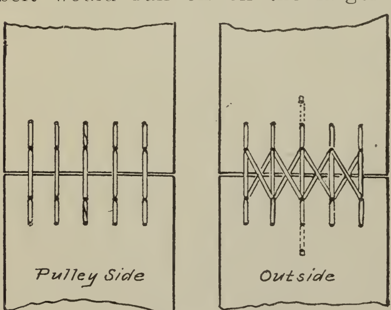


FIGURE 68.

Pulleys.—The friction between a belt and an iron pulley is much less than it is if a wood pulley is used or an iron pulley covered with leather or rope. Where considerable power has to be transmitted through a small sized pulley, it is customary to lag the pulley with leather and thus prevent the belt from slipping. It is

important in covering a pulley, to draw the covering very tight and fasten it so that it cannot work loose. If it is not drawn tight, it will soon come off. Some pulleys are cast with dove tail grooves into which pieces of wood are driven. These pieces of wood hold the nails which keep the covering in place. Other pulleys are made with several rows of holes which are intended to receive the rivets which hold the covering in place. If leather covering is used, it should be soaked in water for several hours before being applied. This will make the leather flexible and stretch it. The ends should then be cut square, the pulley locked in place, and one end of the lagging either nailed or riveted to the pulley. It should then be drawn tightly to the pulley and the next row of nails or rivets inserted, etc., until the pulley is completely covered. A clamp consisting of a couple of pieces of wood can be fastened to the lagging, and the pressure be applied by means of a lever over the end of the clamps and under the shaft. If the lagging is drawn up tightly and drawn in place while wet, it will shrink and become very tight when it is dry. There is much less danger of the belt slipping if the pulley is lagged, than if it is bare. Lagging a pulley increases its size and decreases the speed, proportional to the increase in diameter.

Most pulleys are made crowning, that is, they are a little larger in diameter at the center than near the edges. The reason for this is that the belt is much less liable to run off than if the face of the pulley were straight. A belt always runs toward the largest diameter of the pulley; that is, if a pulley were made cone-shaped, the belt would run off on the larger side of the pulley, provided, of course, that the shafts of the two pulleys are parallel. In the case of a crowning pulley, both edges of the belt tend to run toward the center and consequently the belt has no tendency to run off from the pulleys. In order for belts to run true, the pulleys should be exactly in line and the shafts to which they are fastened should be exactly parallel. It is always advisable to run the machinery in such a way that the lower side of the belt shall be the tight side, as in this way the belt will be in contact with the pulleys through a larger arc, because the weight of the upper half of the belt which is the slack side, will cause the belt



For Heavy Belts
FIGURE 69.

to hug the pulleys; if the lower side is the slack side, the weight of the belt will cause it to fall away from the pulleys.

In figuring the speed of the pulleys, their circumferences need not be considered. All that is necessary to know is the diameters, because the circumferences are proportional to the diameters. If one knows the speed of the driving pulley, the diameter of the driver and the diameter of the follower, it is easy to figure the speed of the follower. The rule is: form a fraction with the diameter of the driver for the numerator, and the diameter of the follower as the denominator, then multiply this fraction by the speed of the driver; the product will be the speed of the follower.

ENGINE EFFICIENCY.

The statement is frequently made that the efficiency of a steam engine at its best is not more than ten or twelve per cent and that generally it is much less. If this is true it means that from eighty-eight to ninety per cent of the energy supplied is lost before any work is done. This is a tremendous loss and the reasons for it are of interest to everyone who uses steam power.

The term *efficiency* may not be generally well understood and so we will state briefly that it means the ratio of the amount of work obtained from a machine to the work put in. It means *output* divided by *input*. Or, in other words, if we put two hundred foot pounds of work into a machine and it delivers only one hundred foot pounds of work then the efficiency of that machine is only $\frac{100}{200}$ or fifty per cent. This definition of efficiency applies to any machine whatsoever, whether it be a steam engine, a gas engine or a jack screw.

A steam engine is a heat engine. Heat is the source of its energy. The larger the engine, the more fuel it takes to run it. The engine that can deliver the largest amount of power with a given quantity of fuel is the most efficient engine. Consequently, in order to get at the ultimate efficiency of a steam engine, and this includes the boiler and all other parts, we must start at the coal pile and take into account, first, the amount of heat energy the coal contains, and second, all of the heat losses that occur before the heat of the coal is turned into useful work. This leads us then to a consideration of the nature of heat and its relation to work.

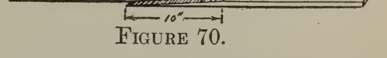


FIGURE 70.

To begin, heat is a condition, or effect. It is not a substance and cannot be weighed although we do have a method of measuring it, which will presently be explained. Heating a substance does not

change its weight, which proves the statement just made, that heat is not a substance.

Sir Humphrey, one of the early experimenters in this field, melted two pieces of ice by rubbing them together, from which he concluded that heat was caused by motion. However, it is well known that substances may be heated without moving them. Nevertheless when a body is heated there is a movement of the particles or molecules of the body because all bodies expand when heated, thus the idea of motion exists even though it be too small to be seen directly. Since heat and motion are inseparable it leads to the conclusion that heat is a form of energy because it requires energy or work to produce motion.

It was suspected for a long time that an exact relationship existed between heat and work but it remained for Dr. Joule of England to discover what this relationship actually is. In 1854 he undertook a series of experiments which culminated in the discovery that one heat unit was equivalent to seven hundred seventy-two foot pounds of work.

A heat unit, or British thermal unit, usually written B. t. u., may be defined as the amount of heat necessary to heat one pound of water through one degree Fahrenheit, or, to be exact, from 62 degrees to 63 degrees Fahrenheit, and according to Dr. Joule's experiments this represents an amount of work equal to raising seven hundred seventy-two pounds one foot high. A few years later Dr. Rowland of Baltimore found the value to be seven hundred seventy-eight foot pounds and this is the value now accepted by all American engineers and is called the *mechanical equivalent of heat.*

To show how all of this applies to the subject of engine efficiency let us consider how the heat of the fuel is changed into work. In the first place, the fuel must be burned in the furnace, water is heated and turned into steam which is piped to an engine and there made to push a piston back and forth. This piston in turn transmits energy through several moving parts before it reaches the fly wheel where it can be turned to useful account. The process is a long circuitous one and inevitably there are many losses.

The first loss arises from radiation from the boiler and its setting. If the boiler is in a closed room where the wind does not strike it and is well jacketed this loss may be made quite small but it is never entirely overcome. In the case of a traction engine working out of doors, it is always large.

The next loss is due to incomplete combustion of the fuel. This may be large, or small, depending upon the skill of the fireman and can be entirely overcome with proper care and intelligence. Then there is a great loss of heat through the smoke stack, carried out by the smoke. For every pound of coal burned there is required, theoretically, twelve pounds of air, but there must be a certain excess of air to insure a sufficient quantity of oxygen and generally from twenty to thirty pounds of air are used per pound of coal. Four-fifths of this air is composed of nitrogen which does no good whatever, but considerable harm, since it must be heated in the furnace and then with a large load of heat cast out through the chimney. The temperature of the chimney gases is from 450 degrees to 750 degrees Fahrenheit, and since each pound of air when heated one degree absorbs one-fourth of a heat unit, very nearly, it can readily be seen that a very large part of the heat of the coal goes to waste in this way without doing any work. This is a loss that can not be overcome although in stationary practice it may be reduced to a minimum by using as small an amount of air as possible, and by placing a feed water heater, or economizer, as it is called, in the base of the chimney and thus cooling the gases as low as possible. To do this, however, requires an expensive equipment which is justifiable only in very large plants. It can not be done with a traction engine. The heat losses so far considered belong to the boiler only. With a poor boiler setting where the air can leak in, or where the boiler is not well jacketed, the total loss may be as much as sixty per cent or as low as eighteen per cent. The latter figure represents about the best that has ever been accomplished in stationary practice, and is much better than can be hoped for in traction engine work.

This brings us now to the losses in the engine itself. The first to claim our attention arises through radiation from the cylinder and steam pipe. If the latter be long or not properly covered, considerable loss may occur at this point, or if the cylinder is not jacketed, the loss may be considerable. The great loss however, and the one that overshadows all others, is due to the heat that escapes with the exhaust steam. In order to appreciate this loss we must first consider the amount of heat that is put into a pound of steam during formation. If one pound of water at a temperature of 32 degrees Fahrenheit be heated to the boiling point it will require 180 heat units and if this boiling water be evaporated into steam at atmospheric pressure it will call for 966 heat units, additional, making a total of 1,146 heat units in each pound of steam at atmospheric pressure, that is, pressure that is not recorded on an ordinary steam gauge. Every pound of steam at atmospheric pressure contains this

amount of heat, and since this is the pressure of the exhaust steam it follows that every pound of steam that escapes at the exhaust as steam carries with it this large burden of heat. Here then is where the principal loss occurs in steam engines. It is in the heat of the exhaust steam and it can not be overcome because the medium used, water, requires so much heat to *change its form* from water into steam, and this is practically all lost in non-condensing engines.

In addition to these heat losses there must be taken into account the losses through friction in the engine itself. These losses in traction engines are never less than four per cent and may range as high as twenty per cent, or even more, depending upon the condition of the bearing surfaces.

Counting from the coal pile and taking everything into consideration it is doubtful if a traction engine will show more than six per cent efficiency under favorable conditions. This means that for every one hundred pounds of fuel burned ninety-four pounds are lost, truly a wonderful performance; and yet it is not much worse than stationary engines of the best grade, which rarely yield more than ten or twelve per cent efficiency. Under the most favorable circumstances, where every precaution known was employed to reduce losses, and with large sized high speed engines, efficiencies as high as twenty per cent have been recorded but very few steam plants have ever reached such a high standard.

Considering the medium we are required to work with, namely, water, it does not seem possible to ever improve the steam engine very much beyond its present condition so far as efficiency is concerned.

Let us now consider the possibilities in a pound of coal from a purely heat basis. A pound of good soft coal will yield approximately 13,000 B. t. u. or 10,024,000 foot pounds of energy. A horse power is equal to 33,000 foot pounds per minute or 1,980,000 foot pounds of work per hour. 10,024,000 divided by 1,980,000 equals 5.06, which shows that theoretically one pound of good average soft coal should yield 5.06 horse power per hour, while as a matter of fact it takes anywhere from one to six pounds of coal to yield *one* horse power per hour in the steam engine.

Gas engines, however, have an advantage in efficiency over the steam engine. Any good average gas engine will yield at least fifteen per cent efficiency and that too in the small sizes while the best gas engines have shown efficiencies under actual test of more than thirty per cent. The reason for this advantage in efficiency is easy to explain. The heat is generated where it is used, in the cylinder, and there are not so many chances for loss to occur. The medium used is air and no energy is required to change its form as is the

case with water. True, there is considerable loss of heat through the jacket water and on account of the exhaust gases and the friction of the engine is considerably larger in proportion than in the steam engine, but its ultimate efficiency is greater than the steam engine nevertheless. Both, however, are wasteful and are depleting the world's fuel supply at an alarming rate.

CARE AND HANDLING OF A TRACTION ENGINE.

The life of a traction engine all through the Northwest is, on an average, about seven years.

Traction engines do less than three months work per year, or a total of less than two years of actual work before they go to the scrap heap. Some engines, it is true, last two or three times as long as this, but this fact only goes to prove, even more forcibly than anything else, that the method of handling is extremely wasteful.

Each of these engines cost anywhere from $2,000 to $2,800, thus making the deterioration amount to from $300 to $400 per year. Figured on the basis of the actual work done the deterioration is greater yet. For example: Suppose the engine works eighty days per year which is a high average, and cost originally $2,800. If it lasts seven years the deterioration is $400 per year or five dollars per day for every day it runs. If the engine runs only forty days a year the deterioration is just twice as much or ten dollars per day.

This amount is altogether too high, and while it is not very complimentary to say it, it is largely the thresherman's own fault. A traction engine ought to last from fifteen to twenty years with anything like decent care. They are well made and contain the best of material. The fault lies with the user.

Poor engineers, poor care, bad water and a desperate desire to keep going at all hazards, tells the story in one sentence.

It pays sometimes to make haste slowly. If anything goes wrong it pays to stop and mend it even if the crew does lie idle for an hour or two. It generally prevents a worse condition a little later and is sure to make the engine last longer. If anything within reason can be done to make an engine last two or three times as long, it ought to be considered.

The writer has made earnest inquiry in every business he is acquainted with to determine the amount of deterioration in equipment and he fails to find anything that can compare in any way with the thresher business as it is carried on at the present time. How long would any manufacturing business prosper if all the machinery had to be replaced every two or three years or less? Yet this is the

average condition among threshermen. Can this condition be improved? Certainly. The remedy is simply better skill in handling the machinery and more intelligent care both during the threshing season and while the engine is lying idle.

It may not be generally recognized, but it is a fact, that an engine standing idle, unless first put in proper shape, deteriorates almost as fast as while working. In other words, all deterioration must not be charged against the actual working time. However, if properly cared for, the deterioration during the time of idleness should be very small.

Now let us consider the means to be adopted to better conditions. First, we must consider the engineer. He should be a master of his business. In addition to being a good engine driver, one who can pull up in line in a twinkling, he should know machinery, and how to take care of it. He should be a careful, painstaking, cool-headed man by nature, and have, through study or experience, learned the foundation principles of steam engineering.

Running a traction engine is a trade by itself and requires a better man than for a stationary engine or a locomotive. A traction engine is a complete power plant in itself which works under the hardest possible conditions. There are too many men rated as "cracker jack" engineers whose reputation is based solely on their ability as engine drivers. They can line up in "no time" but do not know enough about how to take care of the engine and boiler.

Engine driving is a part of the business, true enough, and ability to do it well counts heavily when a big crew is waiting, but if care and management and a thorough knowledge of the engine is not combined with it, it is not enough by a long ways. It pays any man who owns a traction engine to put a really good man in charge, even if he has to pay double the usual wages. If this statement seems extravagant, think of that deterioration charge and then figure again.

The next thing to be considered is the care of the engine in the field. It is the engineer's duty to watch everything carefully and see that every part is in good adjustment. But right here a warning is necessary. It is not a wise thing to start out with a monkey wrench whenever you hear a knock or pound and tighten all the bearings. A little knock does not hurt very much, and any way, it is poor policy to try to locate anything of that sort by ear. The only sure way to locate a knock is either to see lost motion or feel it, and no adjusting should be done until it is located in this way. Then never try to take out all the pound at one time. Take out some today, a little more tomorrow, and thus let the bearing gradually

adjust itself to the change caused by tightening the boxes. If all of the knock is taken out at once the chances are ten to one that the box will get hot.

A good traction engineer, moreover, does not let many things get out of order very badly. He goes over his engine with a bit of waste every time it stops and wipes it up just as a locomotive or stationary engineer does. He takes pride in the appearance of his engine and while wiping up and keeping things looking well inspects every bolt and nut and detects any fault before the consequences can become serious.

Threshing is a dirty business, to be sure, but a good engineer who takes a pride in his business will keep his machine looking pretty well just the same, and, by the way, a man who doesn't take a pride in his business is a pretty poor specimen.

The inside of the boiler needs just as much attention as any other part. It should be kept free from mud and scale. If it isn't kept clean it will be hard to fire and there is danger of overheating the metal. Mud can always be washed out with a force pump and a nozzle on the end of a hose, working from the front end of the boiler back. Scale is harder to handle.

Water containing scale-making substances may be perfectly clear and even sparkling. One can not tell by the appearance of water whether it is good for boiler purposes or not. Cold water is a great solvent, that is, it will dissolve most mineral substances to some extent, therefore water generally contains some of all the minerals found in the soil through which it flows. If the soil contains lime, the water contains lime, and if magnesium or alkali is in the soil it will also be found in the water.

The worst substances in the water that an engineer has to contend with are the carbonates and sulphates of lime and magnesium. These form a hard rock-like scale, especially if there is mud or some other substances present.

In cold water these substances are dissolved in the water, but when the water is heated to the boiling point, 212 degrees, the carbonates are no longer held in solution. When the water is heated to 280 degrees the sulphates are no longer soluble and they fall.

There are a number of boiler compounds on the market that will purify water containing these substances, which, if used judiciously, will bring good results. The basis of most of these compounds are caustic soda, soda ash, and tannic acid compounds, made mostly from the exhausted liquor from tanneries.

For lime water soda ash or sodium phosphate compounds are good and are safe and harmless.

Kerosene is also used with good effect, both to prevent scale and to remove it. As a preventative it should be used sparingly, because it has a tendency to work into the joints and cause them to leak by dissolving out the particles of rust. A pint per day for a 25-horse power boiler is enough. It should be introduced continuously with the feed water.

To remove scale, it should be put in on top of the water when the boiler is cold, then the bottom blow off opened and the water withdrawn. The oil will settle on the scale and soak in after which some of it may be jarred loose and washed out. Some engineers drain the boiler and then when cold, build a light fire on the grates, claiming that the expansion of the metal will crack the scale loose. Care must be taken if this remedy is tried, not to overheat the boiler.

There seems to be no compound that is safe to use for the alkali water found in many parts of the West. It is the substance that makes boilers foam so badly. Any acid, it is true, will neutralize the alkali, but such a remedy is very dangerous because it corrodes the boiler so badly. The best thing to do in this case is to blow off some of the water two or three times every day and so keep the percentage of impurities as low as possible. Indeed, this is a good rule to follow with all bad feed water.

The steam rising from water is pure, that is, it does not contain any of the impurities that make scale. These all remain in the water, consequently all of the alkali or other impurities of all of the water fed to a boiler will remain therein unless some are blown out, and the result is that the remaining water in the boiler keeps getting more and more impure. A good rule to follow then is to blow out a portion of the water each day or, where alkali is in the water, several times a day.

At the end of the season's run the engine should be put in shape so that it will not deteriorate much until the next season. First of all it should be housed in a good dry place. A man can not afford to own a traction engine if he can't afford a good shelter for it. Rain or snow or moisture should not touch any part of the engine. Rust is caused by moisture in the presence of air.

The boiler should be drained and thoroughly dried. The cylinder and valve should be oiled, all pipes should be drained, and the brasses removed. The packing should be removed from the piston rod stuffing box, and all the bright portions of the metal given a coating of hard oil, or better yet, coated with a mixture of white lead and tallow. The pump, if there is one, should be taken apart and dried and given a coat of hard oil. It need not be put together again until next season.

Then the fire box, ash pit, and combustion chamber should be cleaned out thoroughly. It is a good plan also to paint the chimney and those parts of the boiler not covered by the jacket, with asphaltum paint. If all these details are looked after conscientiously the engine will be in good shape for the next season.

A traction engine needs intelligent care all the time, if the owner wishes to make the most of his investment.